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LANDING TECHNIQUE ASSESSMENT UTILIZING LABORATORY-BASED LANDING AND SIMULATED BASKETBALL LANDING TASKS

by

HIROMI KOWATA

(Under the Direction of Barry A. Munkasy)

ABSTRACT

Context: The Landing Error Scoring System (LESS) is a two-dimensional landing technique assessment tool that is readily available to clinicians. However, the LESS merely assesses a contrived landing, rather than dynamic, complex movements that may occur during actual athletic performance. **Objective:** To compare the LESS scores and knee joint kinematics between the LESS vertical-drop jump (DVJ), and two simulated basketball landing performances, jump-stop jump shot (JS) and rebounding (RB).

Design: Prospective, cross-sectional study. **Setting:** An intramural basketball court.

Participants: Twenty-five female recreational basketball players (Age: 20.96 ± 1.70 , Height (cm): 166.07 ± 9.10 , Weight (kg): 68.54 ± 12.17). **Intervention(s):** Participants performed the DVJ, JS, and RB. All landing performances were video-recorded and kinematics were analyzed using Dartfish. **Results:** LESS scores were significantly different between DVJ (5.97 ± 1.43) and JS (8.75 ± 0.94) ($p < 0.001$), DVJ and RB (7.33 ± 1.02) ($p < 0.001$), and JS and RB ($p < 0.001$). Knee flexion angle (KFL) at initial contact (IC) was significantly different between JS ($25.62^\circ \pm 4.80^\circ$) and RB ($21.06^\circ \pm 4.84^\circ$) ($p < 0.005$), maximum KFL was significantly different between DVJ ($89.55^\circ \pm 12.14^\circ$) and JS ($82.54^\circ \pm 10.60^\circ$) ($p < 0.001$), and DVJ and RB ($21.06^\circ \pm 4.84^\circ$) ($p <$

0.001). Knee abduction angle (KAB) at IC was significantly different between JS ($5.96^{\circ} \pm 3.85^{\circ}$) and DVJ ($1.94^{\circ} \pm 3.22^{\circ}$) ($P < 0.001$); JS and RB ($3.10^{\circ} \pm 3.26^{\circ}$) ($p < 0.001$); and, no significant difference was found in KAB at maximum knee flexion (Max) between any combination of the three landings. **Conclusions:** Female recreational basketball players employed a different landing strategy between a controlled landing and simulated basketball landing tasks. The simulated basketball landings might better help identify athletes with poor landing technique, and are at higher risk of sustaining ACL injuries.

INDEX WORDS: Anterior cruciate ligament, Prevention, Screening, LESS, Landing, Basketball

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CHAPTER 1

INTRODUCTION

Prevention of the anterior cruciate ligament (ACL) injury is of significance due to the substantial incidence rate, prolonged recovery, increased odds of recurrence, and complications including chronic knee instability, and the potential early onset of osteoarthritis.¹⁻⁴ An individual with an ACL tear history has a ten times greater risk of developing osteoarthritis.⁵ Over 250,000 ACL injuries occur annually in the United States,^{6,7} with nearly \$3 billion annual medical costs for both surgery and rehabilitation.⁷ More than 20% of the total annual costs, \$650 million, arises from high school and collegiate female athletes.⁸ The initial incidence rate is 0.017% to 1%, however, that of sustaining subsequent ACL injury, especially in younger individuals, is considerably higher — 6% to 25%.^{3,4,9} Basketball has a high ACL injury rate that is likely due to the sport's athletic movements, such as landing and cutting, which place tremendous stress on the ACL.^{10,11}

The non-contact ACL injury rate is remarkably high compared with the contact injury rate — as high as 84% of all ACL ruptures.^{1,10,12,13} A non-contact ACL injury typically occurs during landing from a jump at or near full hip and knee extension, and during cutting or change in direction maneuvers that have abrupt deceleration.^{10,11,13,14} Landing is the most common injury mechanism in terms of basketball movements, such as jump-stop jump-shot (JS) and rebounding (RB), and ACL injury is more likely to occur during multiplanar as opposed to uniplanar movements.^{15,16} Kinematic changes at the knee joint that increase ACL loading are decreased knee flexion (KFL) (less than 30°) and hip flexion angles, tibial and hip internal rotation,¹⁷⁻²⁰ and increased knee abduction (KAB) angle.²¹ Excessive anterior tibial shear force

which can tear the ACL may result from decreased KFL angle at initial contact (IC) and throughout the landing phase during athletic maneuvers.^{22,23} These kinematics changes due to the anterior tibial shear force are conducive to increasing KAB angle that is considered significant ACL injury predictor.²¹ The combination of decreased KFL, and increased KAB and hip internal rotation has been recognized as dynamic knee valgus.²¹ Individuals exhibiting dynamic knee valgus, seen more among women than men, are considered at greater risk of ACL injuries.^{21,24,25} Knee joint kinetic changes, which lead to greater ACL loading, include increased KAB moment and internal tibial rotational moment.^{21,26,27} These multi-planar mechanical alterations evoke further kinematic and kinetic change, including, increased anterior tibial shear force induced by excessive quadriceps contraction with decreased hamstring co-contraction. These alterations in kinematics and kinetics cause undue anterior tibial translation, resulting in an ACL injury.^{23,28} It is thought that it is not the forces generated by both the quadriceps and hamstring, but rather recruitment rates of those muscles that are crucial factors potentially contributing to ACL injury.^{21,29,30} Another critical contributing factor to ACL injury involves the trunk kinematics with associated kinetic changes. When landing with decreased trunk flexion, more erect posture is created and the center of mass is located posterior to the base of support, along with the foot contacts on the ground with reduced ankle dorsiflexion.^{31,32} This results in increased ground reaction force and augmented quadriceps and trunk flexors activation to recoup the unstable posture, which ultimately magnifies the anterior tibial shear force that loads the ACL.^{31,32} Deficits in core proprioception and trunk displacement in the frontal plane lead to diminished core control, which is identified as an ACL injury predictor that applies only to female athletes but not male athletes.^{33,34} During puberty, females increase adipose mass; while, males gain muscle mass.³⁵ The increased ratio of fat to muscle mass alters

the location of female center of mass,^{35,36} which disturbs their proprioceptive system.^{35,36}

Though, there is no significant difference in injury rate between genders in the pre-puberty period,³⁷ female ACL injury rate spikes during or post-puberty potentially due to the imbalanced neuromuscular control.^{1,38} Conducting risk assessment is crucial to identify those who are at higher risk of sustaining an ACL injury and developing personalized preventative training programs to reduce that risk.

Even with effective interventions that include plyometrics, balance, and agility training that are currently available, the ACL incidence rate remains high.³⁹⁻⁴⁴ Screening tools to potentially identify at-risk individuals based on three-dimensional motion analysis are the gold standard,⁴⁵ however, to conduct a screening test on a high-volume of athletes in a clinical setting, such as a college, using the costly and time-consuming biomechanical computer-based analysis is impractical.^{20,46-48} To reduce the incidence of ACL injuries that have been on the rise,⁴⁹⁻⁵¹ practical screening tools that eliminate those financial and time constraints are needed. Screening tests that assess landing techniques to possibly identify the individuals who are at higher risk of sustaining ACL injury have been developed.^{52,53} In research settings, the drop vertical jump is commonly utilized to scrutinize landing techniques that are associated with the ACL injury. The drop vertical jump mimic the actual ACL injury situation that involves sudden change in direction commonly seen in basketball landing maneuvers, including JS and RB.⁵⁴⁻⁵⁶ The Landing Error Scoring System (LESS) is a reliable two-dimensional assessment tool involving a drop-vertical jump (DVJ) that requires only two video cameras recording frontal and sagittal movement planes.^{21,46,52} For the LESS, participants perform a drop-jump from a 30 cm-high box that is set at 50% of their height away from the landing area, followed by an immediate vertical jump. The first landing before the maximal vertical jump is analyzed and the

second landing after the maximal vertical jump is discarded. Advantages of the LESS are that it is (1) a comprehensive multiplanar assessment tool with explicit descriptions of scoring items; (2) time-efficient, and (3) administrable by a novice examiner.⁵⁷ Since scoring each item is dichotomous in nature, scoring variability is reduced.⁵² The LESS is an applicable assessment tool for basketball players due to the common characteristics between a DVJ and basketball landing.^{11,52} Therefore, the LESS provides clinicians with a practical way of assessing individual landing technique and may guide them to determine the necessity for an intervention program.

Tuck jump assessment (TJA) also has been identified as a practical screening tool that is potentially capable of identifying landing biomechanical deficits derived from the neuromuscular imbalances associated with ACL injuries.^{8,53} This assessment involves 10 seconds consecutive tuck jumps, a short-bout of plyometric exercise, which requires higher coordination and effort.⁵³ The neuromuscular deficiencies identified by the TJA can be categorized into one of the following dominances; ligament, quadriceps, leg, or residual injury deficits, trunk, and technique perfection.⁸ Similar to the LESS, the TJA is quite simple and clear descriptions of scoring items that enable clinicians to visually assess the performance and target the at risk individuals who would most benefit from neuromuscular training program.⁵³ However, the TJA is a successive plyometric motion that is not performed in the actual basketball game situations. Biomechanical technique deficits that can be observed during landing in the real-world scenarios may be more applicable to identify those at high-risk of sustaining ACL injury. The LESS

Though the LESS is a reliable and simple screening tool, it is a laboratory-based test which assesses contrived movements – not sport specific movements. The LESS does not

involve a ball and the majority of ACL injuries among team sports tend to occur when an offensive player possesses a ball during a game situation.⁵⁸ Furthermore, during sports participation, such as playing basketball, a player's attention is divided between the basketball goal, opposing players, and the ball – not necessarily the landing motion after a jump shot or rebound.¹¹ Actual athletic performance differs from the LESS protocol. For instance, kinematics and kinetics of sidestep cutting that involves a mock defender demonstrated increased medial ground reaction forces, greater hip abduction, and increased knee valgus in a real world setting compared to a laboratory simulation.^{59,60} Integrating dribbling to sidestep cutting increases KAB angle during an earlier stance phase.^{60,61} Interestingly, greater KFL angle, which is commonly deemed as a preferred technique in athletic performance,^{23,62,63} can be attained when dribbling is incorporated into sidestep cutting compared to non-dribbling situation. Simulated real world performance might elicit kinematics and kinetic features associated with ACL injury that cannot be observed in laboratory-based assessment. Both sagittal and frontal plan knee kinematics that place individuals at risk of ACL injuries can be successfully measured with two-dimensional methods that typically investigate the variables at IC and at maximum knee flexion (Max). Kinematics at IC is usually studied since the instance represents close to when actual ACL injuries occur,^{58,64} and relationship between the athletic maneuvers and non-contact ACL injuries have been examined looking at IC.⁶⁵ Meanwhile, kinematics at Max is investigated because it is considered the most out-of-control position of the knee during landing.⁵⁴ Both IC and Max measured by two-dimensional methodology has been shown to have correlation with three-dimensional joint kinematics measure.^{21,66} The kinematics and kinetics in the context of ACL risk screening of simulated basketball landing performance was not found.

Therefore, the purpose of this study was to compare the differences in LESS scoring between a laboratory-based LESS DVJ, and two simulated basketball landing performances, JS and RB. It was hypothesized that female recreational basketball players' LESS scores would differ under the three landing conditions. Another purpose of this study was to compare KFL and KAB angles at IC and at Max during these tasks. It was hypothesized that KFL and KAB angles at IC and at Max during these tasks would be different, which may indicate the need for a more applied clinical assessment tool.

CHAPTER 2

METHODS

I Participants

Thirty female recreational basketball players between the age of 18 and 25 years were recruited as participants from a college institution (Age: 20.96 ± 1.70 , Height (cm): 166.07 ± 9.10 , Weight (kg): 68.54 ± 12.17). (Appendix C, Table 1) The number of participants was determined by conducting a power analysis, which indicated that a minimum of 25 participants (effect size = 0.80, $\alpha = 0.05$) was required for a power of 0.8. The inclusion criteria for the participants were the following: those who have at least one year of basketball experience either high school or college level but not currently participating in an intercollegiate basketball team, and those who engage in physical activity at least three times a week, 30 minutes per session.^{67,68} Participants were excluded if they reported previous history of ACL injury,^{69,70} any other lower extremity injuries that resulted in chronic instability at the ankle, knee and hip,⁶⁹ current lower back injuries,^{33,34,71} any medical or neurological conditions (e.g., respiratory disorder or paresthesia) which may interfere with participation in the study,^{28,72} and those who have undergone ACL injury prevention programs.^{73,74} All participants read and signed the informed consent before participating in this study. Institutional Review Board approval was obtained for the study protocol prior to implementing the investigation.

II Instrumentation

The LESS assessment tool has demonstrated good to excellent inter-rater (ICC=0.84) and intra-rater (ICC=0.91) reliability and validity.⁵² In addition, expert versus novice inter-rater

reliability of the assessment tool has been reported as excellent (ICC=0.84).⁵⁷ The technique errors of the DVJ task were scored based on a 17-scale scoring system by reviewing the performance videos.⁵²(Appendix C, Figure 1) Scoring items are based on pathomechanical movements that potentially lead to ACL injury. The LESS scores (maximum 17) are roughly categorized into four landing technique levels: excellent ($4 \geq$ LESS score), good ($4 < \text{LESS score} \leq 5$), moderate ($5 < \text{LESS score} \leq 6$), and poor ($6 < \text{LESS score}$).⁵² Dartfish ProSuite software (Dartfish Ltd, Gribourg, Switzerland) was utilized to analyze kinematics of the LESS DVJ and basketball performances.

III Procedures

All participants completed a medical history questionnaire in order to ensure their eligibility to participate in this study (Appendix C, Figure 2). Participants were required to wear T-shirts and shorts, attire they usually wear when playing basketball. However, if the clothes are excessively loose, participants were asked to change into tighter clothes that do not restrict their motions or prevent them from playing as normal. Participants wore shoes that they routinely use to play basketball to help ensure regular, natural performance. In this study, 3 out of 25 participants were asked to change their attire. Kinematics and lower extremity positions were assessed based on the LESS protocol by reviewing videos specifically for knee, hip, and trunk flexion angle, lateral trunk flexion angle, knee abduction angle, stance width, and foot position (foot internal or external rotation). Kinematics assessed with the LESS protocol were defined as follows: *knee flexion*, the angle between the lines drawn from the greater trochanter through the midpoint of lateral knee joint line and the lateral malleolus to the midpoint of lateral knee joint line; *hip flexion*, the angle between the lines drawn from the center of the lateral neck

through the greater trochanter and from the midpoint of lateral knee joint line to the greater trochanter; *trunk flexion*, the angle between the vertical line through the greater trochanter and the line from center of the lateral neck to the greater trochanter, and *lateral trunk flexion*, the angle between the vertical line through the umbilicus and the line from the center of suprasternal notch to the umbilicus. Regarding knee abduction angle, the LESS protocol only assesses whether KAB is present, rather assessing actual angle.⁵² The presence of KAB was determined based on where a vertical line drawn through the center of the patella would run.⁵² If the vertical line goes through the mid-foot at IC or it goes through the first phalange at Max, KAB angle is considered present. Stance width, whether it is narrower or wider than the shoulder width, was determined by assessing the foot position medial or lateral to a vertical line drawn from the acromion process. Foot internal or external rotational angle was assessed by drawing lines from the center of the ankle mortise through the third phalange at IC and at Max. The rotational angles were determined by comparing those two lines at the two different times.

For the selected kinematic variables assessed, angles were defined as follows; *KAB*, the angle between the lines from the center of the patella to the center of the ankle mortise and from the antero-medial thigh to the center of the patella, which was subtracted from 180 degrees, and the *KFL* angle which was defined similar to what was described in the LESS protocol. To aid in landmark identification, markers (athletic tape) that represent anatomical landmarks were placed on the following areas: the acromion process, anterior-superior iliac spine, greater trochanter, antero-medial thigh, midpoint of lateral knee joint line, center of the patella, center of the ankle mortise, lateral malleolus, and the distal end of the first and third phalanges. Other markers included the center of the lateral neck, suprasternal notch, and umbilicus. All markers

were placed either directly on the skin or over the clothes. All participants' static stances were recorded prior to the tests to normalize for anthropometric variations.

DVJ Assessment

Each participant underwent the LESS assessment at a basketball gym in the recreational activity center. The LESS was conducted by having participants perform a DVJ from a 30 cm-high box that is set at an individually adjusted distance, 50% of their height away from the landing area, followed by an immediate vertical jump.⁵² The dominant-limb (which is self-reported as the preferred kicking leg) was the one primarily assessed to simplify the measurement process.⁵² Prior to the screening test, participants were instructed to position their feet at shoulder width on the box, align toes in neutral and perpendicular to the front edge of the box, and land on the target area by shifting their weight forward rather than jumping forward.^{57,75} They were then instructed to perform a maximum vertical jump immediately after landing from the drop jump. The maximum vertical jump in this study was performed as they mimic taking a jump shot — instead of going for a rebound, which is originally described in the LESS protocol by the developers.⁵² The condition of maximum vertical jump was modified in order to make the condition on maximum vertical jump same as the two simulated-basketball landing tasks that are described in next section. Participants were allowed to practice the DVJ as many times as needed to become familiar with the task.⁵² Average practice trials were 2~3 times for this study. A trial was considered successful if the participant (1) jumped off of both feet from the box; (2) jumped forward to reach the target landing area, (3) jumped vertically as high as possible; and (4) executed the task in a smooth manner.⁵² Neither feedback nor coaching cues was provided on their landing technique, except for an instruction that

participants are required to focus on jumping as high as possible immediately after the landing from a drop-jump.⁵² If the trial was determined to be unsuccessful, participants were asked to repeat the task without any other instructions.⁵² Each participant was typically asked to re-perform once or twice. The first landing after the drop jump was the one analyzed.⁵² The LESS scores (maximum 17) were categorized into four landing technique quality groups: excellent ($4 \leq \text{score}$), good ($4 < \text{score} \leq 5$), moderate ($5 < \text{score} \leq 6$), and poor ($6 < \text{score}$).⁵²

The average of the three successful trials were used for data analysis.⁵² Two standard HDV video camcorders were located to capture both sagittal and frontal views of the movements.⁵² The sagittal and frontal view cameras were set 8.0 m and 7.0 m apart from the side and front of the target landing area, respectively. The cameras were secured on leveled tripods set at 1.22 m above the floor.⁵² (Appendix C, Figure 3) With the original LESS protocol, the cameras were set 3.45 m apart from the side and front of the target landing area. In the current study, the camera setting was accommodated to meet the requirement of simulated basketball landing task. Camera shutter speed was set at 1/500 s.

Basketball Jump-Landing Tasks

All participants were asked to perform two different jump-landing tasks that are predominantly performed during a basketball game: a jump-stop jump shot (JS) and a rebound (RB). With respect to a JS, participants began dribbling from about 5 m perpendicularly behind the take-off line, took off at the take-off line that was located at a distance 50 % of the participant's height away from the free throw line, followed by double-legged jump stop at the free throw line, then took a jump-shot as they normally would. The only instruction given for the jump shot was that participants perform a double-leg stop-landing before the take-off to

make a shot, and land as perpendicular to the frontal camera as possible. If participants landed diagonally to the frontal camera, they were asked to perform again. Practice was allowed as many times as necessary for the participant to become familiar with the task. Two cameras were placed outside the basketball court to record both sagittal and frontal planes of motions. One camera was set perpendicular to the free throw line, 1.0 m away from the side line, which is 8.0 m away from the landing area. The other camera was set approximately 2 m away from the middle end line, perpendicular to the basketball goal, at the end zone, which is 7.0 m away from the landing area. (Appendix C, Figure 4) Camera shutter speed was set at 1/500 s.

With regard to the RB, the basketball was set at a height of 30 cm above the tip of the participant's finger (the third phalange) in order to create an equivalent condition to the DVJ. The ball was secured via a rope hung off a stanchion (Vertec Jump Measuring Device, Gill Athletics Inc, Champaign, IL, U.S.A.). Magnets were attached to the ball and the bottom edge of the rope, which allowed the ball to be detached when the participant rebounded. The ball was set at a distance, 25% of the participant's height away from the take-off line, which resulted in jumping over the same distance as the LESS protocol establishes — 50% of the participant's height away. (Appendix C, Figure 5) Participants took 2~3 steps when approaching the take-off line. They took off at the take-off line, grabbed (rebounded) the ball, landed with double legs, followed by a maximal vertical jump as they take a shot. Participants were instructed to perform a two-handed rebound and double-legged landing. They were also be instructed to land as perpendicular to the frontal camera as possible for the analysis purpose.

Three successful trials were conducted for both the JS and RB. All three landing performances, the DVJ, and JS and RB were performed on the same day. The order of testing of

each performance was randomized so as to control for effects of fatigue. Warm-up exercises that each participant routinely performs were allowed prior to the landing assessments.

Perspective Error Assessment

The extent of perspective errors that could occur with two-dimensional analysis on knee frontal and sagittal plane angles due to the effects of lower extremity rotation was measured prior to conducting the investigation. This assessment was expected to minimize the errors and maintain analysis accuracy. In this pilot study, the effect of foot rotation on frontal plane kinematic measurement was investigated, since the foot rotation is clearly identifiable with visual inspection and is affected by other joint rotations, thus accounting for not only one joint but multiple joint rotational effects.⁷⁶ Based on the results obtained from this pilot study, cut-off angles for foot rotation, 20° of both internal and external foot rotations, were established. The 20° window would limit the analysis errors on knee frontal plane and sagittal plane angles within $\pm 5^\circ$. Therefore, the current study could relatively exclude the effect of outliers regarding KAB and KFL angles.

IV Data Analysis

A prospective, cross-sectional study was performed on the collegiate female recreational basketball players. Independent (predictive) variables to address the first purpose of this study, which is to compare the differences in LESS scoring between the laboratory-based landing task and two simulated-basketball landing tasks, were the three different landing conditions; DVJ, JS, and RB. Dependent variables that were analyzed included the LESS score of the three aforementioned landing performances. The LESS scoring sheet may be found in Figure 1

(Appendix C). The lower the score, the higher the quality of landing technique utilized.

Independent variables for the second purpose were also the three landing conditions.

Corresponding dependent variables were two-dimensional KFL and KAB angles at IC and Max for each landing skill.^{24,46,77} The level of significance was established a priori at $p \leq .01$. All statistical analyses were performed with SPSS for Windows.

Inter- and Intra-Rater Reliability Assessment on the LESS

Inter- and intra-rater reliabilities were investigated to ensure the reliabilities of the scores using the LESS for DVJ, JS, and RB. Inter-rater reliability was assessed by two raters – the lead researcher and a certified athletic trainer (ATC) who had almost the same years of clinical experience as the lead researcher. The ATC was provided with a learning session based on the online powerpoint presentation of the LESS, and practice time in order to become familiar with the scoring system. The two raters scored the three landing tasks of four participants by watching their videos to determine inter-rater reliabilities for each landing task. The lead researcher scored the same four participants' landings one week later again to assess intra-rater reliability. Intraclass correlation coefficients (ICCs) were utilized to determine both the inter- and intra-rater reliabilities for each landing task.

Inter- and Intra-Rater Reliability Assessment on the Dartfish

To ensure the reliability for two-dimensional analysis of knee joint kinematics using Dartfish, inter- and intra-rater reliability assessment was also undertaken. The same ATC who participated in the LESS scoring reliability assessment underwent inter-rater assessment for Dartfish. The ATC was given instructions of how to analyze the selected angles – KFL and

KAB angles at IC and Max — by the lead researcher, then both analyzed these angles for three landing tasks of four participants. The lead researcher analyzed the angles again a week later. ICCs were also utilized to determine the inter- and intra-rater reliabilities for the two-dimensional analysis of knee joint kinematics of each landing task.

V Statistical Analysis

Means and standard deviations were calculated for demographics (Appendix C, Table 1). One-way analysis of variance (ANOVA) with repeated measure was used to compare the differences in LESS scores for the three landings. Simple contrast was performed post-hoc, if significant differences existed. ANOVA with repeated measure was also utilized to compare differences in KFL and KAB angles at IC and Max between the three landing maneuvers. Simple contrasts were used post hoc in the presence of significant differences.

CHAPTER 3

RESULTS

Inter- and Intra-Rater Reliability

Both inter- and intra-rater reliabilities of the LESS scoring and Dartfish analysis were good to excellent. The ICC values for inter-rater reliabilities for the LESS scores were 0.99, 0.93, and 0.97 for DVJ, JS, and RB, respectively; while, the ICC values for intra-rater reliabilities for the LESS scores were 0.99, 1.00, and 0.96 for DVJ, JS, and RB, respectively. (Appendix C, Table 2) The overall inter-rater reliability on the Dartfish examining KFL and KAB angles at IC and Max ranged between 0.84 and 0.99; meanwhile, the overall intra-rater reliability ranged from 0.83 to 0.99. The detailed inter- and intra-rater ICC values can be found in Table 3 (Appendix C).

A total of 31 participants were tested, however 6 participants were excluded from the data analysis due to the following reasons: participants were unable to perform the tasks as instructed, for instance, they were heavily focusing on taking off at the determined take-off line, which caused them to adjust the number of steps taken before taking off and perform unnaturally; and, especially for JS; participants were unable to land within the 20 degree of foot rotation window, which did not allow the researcher to analyze accurate knee kinematics. Thus, a total of 25 participants were included for data analysis.

LESS Scores

The first research question of this study was whether female recreational basketball players would have different LESS scores between a laboratory-based landing and the simulated-basketball landing tasks. The LESS scores on each task were significantly different

($p < 0.001$; $F=53.94$) between the DVJ and JS (effect size (ES) =1.94), DVJ and RB (ES=0.95), and JS and RB (ES=1.45). (Appendix C, Tables 4 - 6 and Figure 6) The average score for the JS (8.75 ± 0.94) was the highest among the three landing tasks, followed by the RB (7.33 ± 1.02) and the DVJ (5.97 ± 1.43). Based on the LESS categorization of landing technique quality, 16% ($n=4$) of participants were classified as excellent (≤ 4), 12% ($n=3$) were good (>4 to ≤ 5), 28% ($n=7$) were moderate (>5 to ≤ 6), and 44% ($n=11$) were poor (>6) on DVJ landing task. All participants were categorized as poor for JS. Ninety-six percent ($n=24$) of participants were categorized as poor for RB with 1 participant considered excellent. (Appendix C, Figure 7)

Knee Joint Kinematics

The second research question of this study was whether female recreational basketball players would elicit different knee joint kinematics between a laboratory-based landing and simulated-basketball landing tasks. The KFL angle at IC was significantly different between JS ($25.62^\circ \pm 4.80^\circ$) and RB ($21.06^\circ \pm 4.84^\circ$) ($p < 0.005$) (ES=0.95). Further, the ES indicated the mean KFL angle at IC for JS was significantly greater than that for RB. (Appendix C, Tables 5 - 7, Figure 8) No significant difference was found between DVJ ($23.37^\circ \pm 6.12^\circ$) and JS, and DVJ and RB. The mean KFL angle at Max was significantly different ($p < 0.001$) between DVJ ($89.55^\circ \pm 12.14^\circ$) and JS ($82.54^\circ \pm 10.60^\circ$) (ES=0.58), and DVJ and RB ($21.06^\circ \pm 4.84^\circ$) (ES=0.52). The mean KFL angle at Max was highest for DVJ, followed by RB and JS. The mean KAB angle at IC was significantly different ($P < 0.001$) between JS ($5.96^\circ \pm 3.85^\circ$) and DVJ ($2.34^\circ \pm 3.22^\circ$) (ES=1.15), and JS and RB ($3.10^\circ \pm 3.26^\circ$) (ES=0.81). No significant difference was found in KAB at Max between any combinations of the three landings. The ES

indicated that mean KAB angle at IC for JS was significantly greater than that for DVJ and RB.
(Appendix C, Table 5,6 and 8, and Figure 9)

CHAPTER 4

DISCUSSION

The purpose of this study was to compare the differences in LESS scoring between a laboratory-based LESS DVJ, and two simulated basketball landing performances, JS and RB. The LESS score results supported the hypothesis that there are statistical differences between the scores for the laboratory-based landing task, DVJ, and the simulated basketball landing tasks, JS and RB. Moreover, the scores between the two simulated-basketball landing tasks, JS and RB, were significantly different. The secondary purpose of this study was to compare KFL and KAB angles at IC and at Max during the three landing tasks. The results indicated that KFL angle at IC for JS was significantly greater than RB; KAB at IC for JS was significantly greater than both DVJ and RB.

LESS Scores. The main finding of the present study was that the LESS scores between each landing were significantly different from each other. The scores indicated that participants demonstrated the greatest number of landing technique errors with JS, followed by RB and DVJ. Our overall mean LESS score and each landing quality group mean LESS score on DVJ, JS, and RB were greater than the previous large study examining LESS DVJ on an incoming freshmen military cohort. The results on landing quality categorization of the DVJ was characterized as having a greater percentage poor LESS score group and fewer percentage good, while percentiles for the excellent and moderate groups were equivalent to the previous large study.⁵² The poor LESS score group occupying the highest percentage among the four groups in the current study corresponds with a previous study.⁵² JS and RB did not differentiate the participants into different landing technique quality groups — all participants were grouped into

poor with JS, and all participants were categorized into poor except for one excellent with RB. DVJ results here distinguished the groups based on landing technique quality that is associated with ACL injury risk, while the JS and RB were unable to differentiate landing technique quality. Moreover, the significantly higher scores in the JS and RB compared to the DVJ implied that the simulated-basketball landing tasks revealed more pathomechanical landing characteristics compared to the laboratory-based landing task. The scoring items that distinguished the simulated basketball landing tasks from the laboratory-based landing performance include (1) trunk flexion angle at IC and Max (scoring item #3 and #14), (2) ankle plantar flexion angle at IC (item #4), (3) symmetric initial foot contact (item #12), and (4) lateral trunk flexion angle at IC (item #6). (Appendix C, Table 9)

More participants initially contacted the ground with erect posture when performing JS and RB. Only 8% of participants had reduced trunk flexion at IC with DVJ (Trunk flexion angle at IC — scoring item #3); whereas, 68% and 76% of participants had reduced trunk flexion with JS and RB, respectively. At Max, with JS, 68% of the participants had reduced trunk flexion (scoring item #14); meanwhile, only 20% and 4% of participants had reduced trunk flexion with DVJ and RB, respectively. Therefore, trunk position remained upright at the Max with JS. Participants initially contacting the ground with an extended trunk position may be explained by their attention variance.¹¹ During playing basketball, players are directly attending to the basketball goal, or defensive players, and not to their body movements.¹¹ With JS, participants initiated this task with dribbling and took a shot immediately after they touched down at the landing area. While dribbling, a majority of the participants, 68% (n=17) looked down to target the determined take-off line, 20% (n=5) of them looked up the goal rim, and the

rest repeatedly looked up and down. Prior to taking off, 92% (n=23) of participants looked at the goal rim, and the rest looked at the goal rim right after take-off. All participants continued to look at the goal until a shot was made. Participant's attention on the goal rim may have led to the upright trunk position to aim for a shot. With the RB task, the upright trunk position at IC may also have been created by aiming behavior. In this case associated with grabbing the ball, rebounding above the head is characterized by looking up with an upright trunk position along with an extended cervical position until IC.

At Max trunk flexion angle (scoring item #14), 68% (n=17) of participants had reduced trunk flexion when performing JS, and the following evidence supports the disadvantageous trunk position, an upright trunk position, at Max. The Max trunk position here is similar to previous studies that basketball players demonstrate near full trunk extension position from beginning to raising the ball to ball release when taking a jump shot.^{78,79} On the whole, for JS and RB, the upright trunk position during landing may be a natural part of performance and advantageous position for basketball players.^{78,79} This suggests that the LESS scoring items for the simulated-basketball landing tasks may need modification.

Landing with an extended or even hyper-extended trunk induces separation of the center of mass from the base of support, creating an unstable trunk position.³¹ This unstable trunk position where the center of mass is located far posterior to the base of support leads to an increased quadriceps muscle contraction to regain balance,⁸⁰ resulting in an increased anterior tibial shear force that contributes to ACL tear.⁸¹ The unstable trunk position was evident in both JS and RB at IC in the present work, and it was still observable in JS at Max. With regard to JS, the unstable trunk position occurred when approaching landing from dribbling, placing the feet

similar to a broad jump,⁶² participants' lower limbs were extending out anterior to the trunk compared to DVJ landing. The feet positioned anterior to trunk at IC were observed in RB after participants grabbed the ball and approached landing, however, the distance between the feet and the trunk appeared to be smaller with RB than with JS. Results here support previous work that suggests the relationship of the center of mass to the base of support during landing may be an essential component of a screening test.³¹ Therefore, a potential LESS modification with simulated-basketball tasks might be assessing the distance between the center of mass and the base of support instead of trunk flexion.

Initial foot position at ground contact with the ankle in a dorsiflexed or flat foot position, commonly seen during broad jump and vertical jump in actual game or game-like situations, has been suggested as a risk factor for ACL injury.⁵⁸ These foot positions reduce the ability to absorb the ground reaction force by triceps surae, resulting in transferring the ground reaction force directly to the knee.^{21,43} In addition, when the triceps surae are unable to function to absorb the GRF, the knee is also incapable of inducing a flexion force to absorb the impact loading by contracting hamstring muscles. This produces reduced KFL angle, thus leading to an increase in anterior tibial shear force and potential ACL rupture.⁸² Distinguishing JS from DVJ and RB, in JS participants here landed with the ankle dorsiflexed or flat foot (scoring item #4), as opposed to the approximately 90% of participants that landed in a plantar-flexed position in DVJ and RB.⁵⁸ A dorsiflexed ankle or flat foot position at IC in JS was consistent with research examining ankle position among the ACL injured athletes at the time of the incidence.⁵⁸

Asymmetrical landing is another pathomechanical risk factor for ACL injuries.⁸ Asymmetry observed when landing indicates that the individual has side-to-side lower

extremity neuromuscular imbalance.⁸ Asymmetrical landings (scoring item #11) were observed in JS (44%), RB (24%) and DVJ (12%). Even though the participants were instructed to perform symmetrical double-legged landing in all three landing tasks, when performing JS it appeared that participants were more familiar with performing a single-legged landing (stride stop). If their landing asymmetries were not due to familiarity with the stride stop but their normal performance, they may have side-to-side neuromuscular differences, and are possibly at higher risk of sustaining ACL injury. Therefore, JS may be more sensitive to identify individuals with neuromuscular asymmetries than DVJ or RB.

A video analysis of trunk and knee positions at the time of ACL injury has demonstrated that females tend to show lateral trunk flexion to the ACL-injured side during landing as the associated side of the knee increases KAB angle.⁶⁴ Lateral trunk flexion induces an increase in KAB moment onto the side to which the trunk laterally flexes.²¹ Both KAB moment and lateral trunk flexion have been identified as ACL injury predictors.^{21,33} In the current work, lateral trunk flexion at IC was slightly more common in RB (60%) than in DVJ (48%) and JS (48%) (scoring item #6). Participants here may have lateral trunk flexion more with RB than DVJ and JS, because after grabbing the ball participants lowered it from above the center of their heads to their dominant hand side to take a shot through the flight phase until IC. This ball lowering motion from the supra-medial position to inferior antero-lateral (either right or left) position might have caused frontal plane trunk movement. In RB, lateral trunk flexion occurred to the side to which participants possessed the ball. Increased knee abduction load can be influenced by arm position during landing.⁸³ The arm movement and lateral trunk flexion may impose greater knee abduction moment during RB. Although, the ball was involved in JS landing

performance and arm position was altered during the landing, compared to RB in which superior-to-inferior and frontal arm movement were observed, in JS posterior-to-anterior arm movement was observed. In addition, lateral trunk flexion that ultimately increases KAB load can be caused by the reduced pre-activation of both trunk and hip stabilizers, which are important for core stability and identified as factors that may influence power performance.⁸⁴ Thus, participants who had lateral trunk flexion might have decreased core neuromuscular control, which may lead to frontal plane trunk imbalance that can increase KAB load, resulting in ACL injuries.^{14,21,34,85} The RB may be the appropriate assessment activity to identify female basketball players with greater risk of sustaining ACL injuries, since lateral trunk flexion is one of the ACL injury predictors that is unique to female.³⁴

Knee Joint Kinematics. There were significant differences in KFL angles between JS and RB at IC, DVJ and JS at Max, and DVJ and RB at Max. (Appendix C, Table 5, and Figure 8) The JS showed the largest KFL angle at IC and it was significantly greater than for the RB task. (Appendix C, Table 5 to 7, and Figure 8) The KFL angle at Max for DVJ was significantly greater than for JS and RB. (Appendix C, Table 5 to 7, and Figure 8) The KFL angle at IC for JS was similar to a previous study examining a similar task, running stop-jump.⁸⁶ The KFL angles at IC in the present study for DVJ and RB were comparable to a previous study investigated DVJ by three-dimensional technique.⁸⁷ The KFL angles at Max found here were similar to previous studies that were conducted using three-dimensional analysis to examine DVJ landing kinematics.^{60,87} The DVJ demonstrated significantly greater KFL angle at Max than JS or RB. (Appendix C, Table 5 to 7, and Figure 8) Greater KFL angle is usually associated with decreased risk of sustaining ACL injuries, since it is assumed that landing with more

flexed knee angle increases hamstring muscle activation, which leads to decrease in anterior tibial shear force induced by quadriceps activation.^{23,63} Collegiate female basketball athletes have demonstrated greater KFL angle when performing drop jump compared to their male counterpart.⁸⁸ In addition, female recreational athletes demonstrated less KFL angle than male recreational athletes during athletic maneuvers, suggesting that female recreational athletes may have smaller KFL angle in actual game-like situations.⁶⁷ In the current study, participants showed greater KFL angle at Max in the laboratory-based landing task compared to the simulated-basketball landing tasks. Combined results from previous studies and the current work indicated that female recreational basketball players may employ a greater KFL landing strategy in controlled landing performance, whereas, they may use less KFL during athletic maneuvers.

The foot completely contacted the ground earlier in the ACL injured athletes than controls in a previous study investigating lower extremity kinematics in actual ACL injury scenarios.⁵⁸ Moreover, KFL angles at entire foot-ground contacted were significantly smaller in the injured-athlete compared to the controls, indicating that flat foot landing may prevent the lower extremity structures from absorbing the ground reaction force.⁵⁸ Landing with decreased dorsiflexed ankle or flat foot increases ground reaction force, since it decreases the force absorption capacity of the triceps surae, resulting in transferring the ground force directly to the knee.⁸⁹ The ACL loading may be different between the three landings, and the JS might show higher ACL loading at IC due to the assumed increase in ground reaction force from the dorsiflexed or flat foot landing.⁵⁸

An ACL injury is estimated to occur shortly after the foot contacts the ground— within the first 40 ms.⁹⁰⁻⁹³ Decreased KFL angle at or near IC contributes to ACL injuries, which can induce substantial knee forces.⁵⁸ Decreased KFL angles at IC observed in the current study across all the three landings indicate that participants here have unfavorable landing technique regardless of different landing performance.

Differences were found here for KAB angles. The JS demonstrated the highest KAB angles both at IC and Max, followed by the RB and DVJ. Significant differences were found in KAB angle at IC between the JS and DVJ, and JS and RB.(Appendix C, Table 5, 6, and 8, and Figure 9) There was no significant difference in KAB angles at Max between the three landings. The act of dribbling in JS might have influenced KAB angle. Female basketball players have showed greater KAB and KFL angles at IC during cutting task with dribbling than without dribbling.⁶¹ These findings are consistent with the present study that showed larger KAB and KFL angles at IC in JS, indicating dribbling in JS influenced the knee kinematics.

Cognitive disturbance may have affected the knee joint kinematics in the three landings. Major differences between the laboratory-based landing and simulated-basketball landing tasks were utilization of a ball, incorporation of dribbling or catching, and take-off and landing at specific area during dynamic motion. When an individual engages in multiple tasks simultaneously, attention is divided.⁹⁴ In the current study, more pathomechanical landing features were observed in JS and RB. With JS, 68% (n=17) of participants were looking down while dribbling, however, shortly before taking off, 92% (n=23) of them looked up and aimed to take a shot. With RB, all participants were looking at the ball when going for a rebound and 72% (n=18) of participants began looking at the goal to aim for a shot as soon as they grabbed

the ball during the flight phase. In contrast, with DVJ, a majority of participants, 84% (n=21), did not look at the goal to mimic taking a shot with maximum vertical jump until after taking off, and among those, 60% (n=15) of them did not look at the goal even until after IC or later. These divided attentions may indicate that participants were focusing on landing during DVJ, while they were focusing on taking a shot during landing when performing JS and RB.

There is no established threshold for KAB angle that causes an ACL injury, since ACL injury is multi-factorial.^{13,16,21,51,95} In general, however, greater KAB angle along with an increased KAB moment, identified as a significant ACL injury predictor, increases the risk of ACL injury.^{11,21,64} Focusing on KAB angle obtained by two-dimensional measurement may provide clinicians with objective information to document pre- and post-intervention improvements. The KFL angles may also be base-lined when conducting ACL intervention program. The LESS scoring item #1, KFL angle at IC, is considered an error if one lands with less than 30° KFL at IC. The decreased KFL angle at IC, an ACL injury risk factor,^{22,23,63} was successfully identified by visual inspection when scoring landing tasks (scoring item #1) (Appendix C, Table 2 and 4) Easily observed KFL angles may assist in giving feedback to the individuals to teach favorable landing technique.

CHAPTER 5

CONCLUSIONS

The LESS identified the differences between a laboratory-based landing (DVJ) and simulated basketball landings (JS and RB). Further, it identified differences between two simulated basketball landing tasks. The JS landing performance may be characterized as having an upright trunk position at IC and Max, dorsiflexed or flat foot at IC, and an asymmetrical landing, compared to the other landings. The RB may be characterized by lateral trunk flexion and an upright trunk position at IC. These findings indicate the pathomechanical characteristics are task specific and mechanism of injury may also be task specific. Simulated basketball landings might be more sensitive to help identify athletes with poor landing technique, who are ultimately considered at higher risk of sustaining ACL injuries. Since basketball involves different jump landings, incorporating both the JS and RB as landing assessment tools may be more practical to detect those who land poorly. Differences for KFL angle at Max and KAB angle at IC indicates that the female recreational basketball players employ different landing strategy in controlled environment and actual game-like situation. Sport-specific tasks associated with ACL injuries may enable clinicians to identify at risk individuals and provide feedback applicable to the skills that they actually use in their sports, preventing the devastating injury.

CHAPTER 6

LIMITATIONS

Perspective error pertaining to out of plane motion might have affected the accuracy in analyzing landing performance using Dartfish. While instruction was provided, torsional motions could still be observed, causing perspective error. Cut-off angles for foot internal and external rotations were set at 20°. When participants landed more than 20° foot internal or external rotation, they performed the task again, thus minimizing the perspective errors.

There is still no consensus regarding the effects of menstrual cycle on ACL laxity, however, the ligamentous laxity may be elicited during certain phases of the menstrual cycle and affect the participant's landing performance (i.e., greater knee abduction angle).

Dribbling speed might have affected the scores and knee joint kinematics for JS. Participants here were instructed to dribble at their comfortable speed. Results of the current study showed that JS had the largest KAB angle at IC, which was significantly different from both the DVJ and RB. In addition, JS had the smallest KFL angle at Max among the three landings, which was significantly different from the DVJ. These findings indicated dribbling speed may have contributed to exhibiting different knee joint kinematics in JS.

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APPENDIX A

DELIMITATIONS

Delimitations of this study were that the participants were only recruited from single college institution. The study was also delimited to the recreational athletes in order to gain at least the minimum number of participants to meet the power analysis requirement. Moreover, the study was exclusive for female participants.

ASSUMPTIONS

Participants followed the instructions provided prior to both the screening test and playing the basketball games, which includes following; (1) no exertional physical activities two hours prior to participation, (2) no alcohol consumption twenty-four hours prior to participation. These instructions were given in order to maintain consistency between participants, moreover, to minimize the effects of fatigue and alertness on their performance.¹⁻³ It was also assumed that participants gave their best efforts in the laboratory and simulated basketball performance studies.

RESEARCH QUESTIONS

Research questions for this study included the followings: (1) do female recreational basketball players have different LESS scores between a laboratory-based landing task and simulated-basketball landing tasks? (2) do female recreational basketball players elicit different knee joint kinematics that are highly associated with ACL injury in the laboratory-based landing than in a simulated basketball landing? It was hypothesized that there would be

significant differences in landing strategies between the laboratory-based landing and simulated basketball landing performances. Second, the selected kinematic variables would be significantly different between the laboratory-based landing and the simulated basketball landings.

APPENDIX B

LITERATURE REVIEW

Overview/ Epidemiology

Prevention is of the highest significance in terms of the anterior cruciate ligament (ACL) injury due to the substantial rise in the incidence accompanied by the increased athletic population, particularly amongst females.^{4,5} ACL injury is notorious for prolonged recovery, increased odds of recurrence, complications, such as chronic knee instability, and early onset of osteoarthritis.⁶⁻⁹ In the United States, the estimated annual incidence of ACL injuries is 80,000 to over 250,000, and the estimate number of ACL reconstruction surgeries is approximately 175,000 annually.¹⁰⁻¹² The cost for surgery and rehabilitation for this injury in the United States is \$2 billion annually.¹¹ Gender disparity is of particular concern when it comes to ACL injury, as remarkable growth in the number of young female athletes is reported over the last three decades. In high school and collegiate sports, there has been approximately 10 times and 5 times greater female participants, respectively, within this timeframe.^{8,12,13} ACL injury commonly occurs in sports that involve jumping, pivoting, and cutting, such as basketball, soccer, football, and skiing.¹³⁻¹⁵ Injury rates are especially high in female basketball players, and female soccer players, 2.8 and 3.2 injuries per 10,000 athlete-exposure, respectively.¹⁶ Although many ACL injury studies have been conducted, there are still many aspects that remain unknown.

Mechanism of the Injury (MOI)

The mechanism of ACL injury is primarily categorized into two types: contact, or non-contact. A contact ACL injury involves a direct blow to the knee joint; whereas, a non-contact

ACL injury mechanism is generally defined as an event occurring without direct contact to the involved knee at the time of injury, which includes other players, exterior structures, or the ground.¹⁴⁻¹⁶ Minimal physical contact to anatomical structures away from the knee, such as shoulders, can be negligible, thus ACL injury that occurs with subtle physical contact is also considered non-contact incidence.¹⁴⁻¹⁶ Regardless of gender, non-contact ACL injury rate ranges from 70% to as high as 84% of all ACL ruptures.^{5,14-16} A non-contact ACL injury quite commonly occurs during the following playing situations: landing from a jump at near or full hip and knee extension, cutting or change in direction maneuvers with abrupt deceleration, and pivoting with near full extension of the knee and the foot fixed flat on the ground.¹⁵⁻¹⁷ There is a tendency for female athletes to suffer ACL injury more from either cutting or single leg landing maneuvers.^{15,17-19}

Many studies identify several theories of non-contact ACL injury mechanisms. Those theoretical concepts based on scientific investigations are described as follows: (1) the combination of valgus force to the knee and internal tibial rotation;²⁰⁻²² (2) decreased flexion of the knee at the initial foot contact on the ground, which creates erect posture and allows quadriceps to be excessively activated while hamstrings activation diminishes and,²³⁻²⁸ (3) increased posterior ground reaction force (GRF) with which the force is transferred directly to the knee instead of the force being absorbed by lower extremity muscles, resulting in increasing the anterior tibia shear force.^{29,30} Many evidences of kinetic and kinematic events that occur during ACL tear advocate a significant emphasis on multiplanar mechanism.^{24,31-33}

Kinetic and kinematic changes that occur in each plane are likened to pieces of a puzzle that lead to an ACL injury. In frontal plane, knee abduction motion has been described as a mechanism of ACL injury in many studies.^{15-17,22,34,35} Though, the knee abduction load can

place stress on the medial collateral ligament (MCL), the incidence of combined ACL and MCL tears are rare (4~27% of all ACL injuries).^{36,37} The reasons why ACL injury occurs without MCL tear can be explained by (1) each ligament's function and property, and (2) difference in tensile force resistance between the two ligaments. Both ACL and MCL function to restrain valgus loads to the knee,³⁸ however, there appears to be a difference in how each ligament acts to the valgus load. It has been demonstrated that when valgus load is applied, the ACL tries to restrict transverse knee joint motion – tibial rotation --, while the MCL restricts frontal knee joint motion -- medial joint opening between the medial tibial plateau and medial femoral condyle.³⁸ With regard to properties, it has been found that the MCL collagen density is substantially greater than the ACL.³⁹ Moreover, when valgus load is solely applied to the knee, the ACL receives the stress in a less advantageous way to resist the load since ACL fiber runs diagonally to the load; meanwhile, the MCL counteracts the load in the optimal way as its fiber runs perpendicular to the load.⁴⁰ Cadaveric studies have shown that the peak valgus load for the ACL to be ruptured was approximately between 640 and 2100 Newtons (N);⁴¹⁻⁴³ whereas, 2300 N for the MCL to be completely torn.⁴⁴ Therefore, those functional and structural anatomy of the ligaments and the varied tensile force resistance indicate that the ACL may fail prior to the MCL by external valgus loading and the MCL can still be intact.

It is noteworthy that the vast majority of ACL tear occurs without MCL rupture.^{29,30} ACL provides a primary restriction on anterior tibial translation (ATT)^{45-47 48} by absorbing approximately 90% of the anterior tibial shear force (ATSF).⁴⁸ Factors that cause ATT significant enough to tear the ACL must be taken into account in understanding the MOI. Excessive quadriceps muscle contractions have been identified as intrinsic factors that generate anterior tibial shear force (ATSF) which contributes to ATT, resulting in placing significant

load to the ACL.^{49,50} The stress to the ACL further increases if the knee is at shallow flexion angle, typically less than 30 degrees.⁵⁰⁻⁵³ Undue stress can be imposed on the ACL by augmented ATSF that causes excessive ATT and may rupture the ACL.⁵² However, as it is plausible that ACL injury is multiplanar mechanism in nature, both ATT and ATSF that occur in sagittal plane are nothing but one of the important components of the MOI.^{24,31,52}

The bone contusion evident by magnetic resonance imaging (MRI) studies provides firm support for multiplanar mechanism theory.⁵⁴⁻⁵⁷ The MRI obtained from patients within six weeks of post ACL injury (considered acute phase) commonly show bone contusions on the posterolateral aspect of the tibial plateau or lateral femoral condyle.^{55,57} The location of the contusions demonstrates the mechanism of the ATT relative to the femur.⁵⁷⁻⁶⁰ The reason why the contusions are observed is that naturally tibial plateau is tilted posteriorly, which induces the convex surface of femoral condyle to slide posteriorly when the knee valgus and tibial internal rotation are combined, thus causing even greater ATT.⁶¹ The evidence of contusions on the particular area also indicates the presence of compression force at the lateral knee -- which creates an open space between the medial tibial plateau and medial femoral condyle --, and the presence of valgus force at the time of the injury.⁵⁴ If ACL injury is caused by kinematic and kinetic events occurred solely in sagittal plane, bone contusions would be seen on both medial and lateral tibial plateau.³¹ Therefore, as the bone contusions typically detected on lateral aspect of the tibial plateau or femoral condyle, ACL injury is more likely to occur in multiplane.

Risk Factors

Predisposed factors for ACL injury are commonly classified into two categories; intrinsic and extrinsic. Intrinsic domain -- factors related to inside the body -- includes anatomical, hormonal, and neuromuscular risk factors; whereas, extrinsic domain -- outside the body factors

-- is composed of environmental risk factors, the type footwear, the type of playing surface, prophylactic device, and level of activities.¹² Identifying risk factors is crucial, which leads clinicians to understand injury mechanism and further leads to develop appropriate interventions that aim at each individual issue associated with ACL injury.

Of the three primary intrinsic risk factors, neuromuscular imbalances have been studied extensively, as they are the ones that elucidate the gender disparity in ACL injury risk and ones that can be modified by implementing specific interventions which target the issue an individual possesses^{62,63} The neuromuscular biomechanical imbalances are grouped into four distinct types: (1) ligament dominance, (2) quadriceps dominance, (3) trunk dominance, and (4) leg dominance.^{62,64,65} Ligament dominance refers to the condition that individuals absorb ground reaction force (GRF) with the joint and surrounding ligaments rather than muscles that are primarily supposed to absorb the intense force. Amplified GRF can be caused by improper activation of posterior muscles in lower extremity that include gastrocnemius, hamstring muscle group, and gluteal muscles.^{63,66} As mentioned in the mechanism of injury section, the foot and ankle, both absorb the GRF. Failure to properly activate the lower extremity muscles in posterior chain, which can result in increased anterior tibial translation force and valgus force, leads to transfer tremendous force to the knee joint and the ligament, thereby increasing the risk to rupture the ACL.⁶³

Quadriceps dominance is recognized as another muscular imbalance, which is predominantly seen among female athletes.⁶² Those identified as this dominance are featured by recruiting primarily the quadriceps rather than hamstrings to stabilize and stiffen the knee joint.⁶⁴ Females tend to activate the quadriceps to counteract the anterior tibial translation. In contrast, males recruit hamstrings to attempt to reduce the translation, which place significant

stress on the ACL. The primary role of the ACL is to prohibit the tibia from translating anteriorly. The quadriceps muscles, the powerful knee extensors, which act as antagonists of the ACL, insert to the tibial tuberosity via the superior and inferior patellar tendons. As the quadriceps contract, they induce the force to move the tibia anteriorly, which place the ACL into a stretched position. Utilizing hamstrings is accounted an ideal, since they are ACL synergistic muscles, in other words, they generate force in posterior direction as they try to prevent the tibia from shifting anteriorly, resulting in decreasing loads to the ACL.

Quadriceps dominance is further illustrated by taking knee flexion angle during dynamic athletic tasks, such as, landing and cutting, into account. As mentioned, decreased knee flexion causes increased anterior tibial shear force and prone to the ACL injury.^{15,17,18,30} Studies based on interview and video analysis revealed that anterior tibial shear force increase with the knee flexion angle between 0 and 30 degrees^{46,52,67}; whereas, cadaveric studies indicated that the greatest anterior shear force to the tibia occurs during the knee flexion ranging from 20 to 40 degrees.^{46,68,69} Peak hamstrings activity is identified between 50 and 70 degrees of knee flexion.⁷⁰ Thus, the decreased knee flexion at the initial contact in landing or cutting appears to be a biomechanical disadvantageous position to react to the anterior translational force induced by the quadriceps muscles.⁷¹⁻⁷³ Gender-disparity in terms of knee flexion angle during athletic tasks has been reported, which is that female athletes employ reduced knee flexion strategy to stabilize the knee joint as opposed to males relying on deeper knee flexion when performing landing and cutting.⁷⁴⁻⁷⁶ The reason for this divergence between genders is that female athletes alter their neuromuscular control following the puberty, which impairs the ability to stabilize the knee joint during dynamic performance.⁷⁷ However, this gender difference seems to be controversial. Later studies found no difference in knee flexion angle between male and female

athletes, or females performed landing or cutting tasks with deeper knee flexion than males.⁷⁸⁻⁸⁰

More recent video analysis study, which investigated mechanism of the injury among basketball players, showed that injured female athletes had greater knee flexion than males at the initial contact on the ground at the assumed moment of the incidence.¹⁸ The disagreement between studies indicates other risk factors that can better predict the ACL injury, such as, valgus movement at the knee joint.²²

Leg dominance is referred as the neuromuscular imbalance and joint kinematics difference between the dominant and non-dominant leg. It is indicated that side-to-side imbalances in muscular strength, muscle recruitment patterns, and muscular flexibility increase the risk of sustaining ACL injury, and the imbalance are even greater in females than males.^{35,81-84} Increased GRF, knee valgus angles and moments due to the inadequate neuromuscular control are deemed as predictors of ACL injury risk in female athletes.^{22,64} In addition, differences in valgus knee angles and moments between the legs are reported as ACL injury risk predictors.²² One study showed that female basketball and soccer athletes demonstrated that dominant side revealed greater valgus moments as well as increased GRF during cutting task.⁸⁵ When performing a drop vertical jump (DVJ), both basketball and soccer athletes received greater GRF on non-dominant side. Between the sports, basketball players showed higher GRF on non-dominant side during DVJ; meanwhile, soccer players had greater GRF on dominant side during cutting maneuver. Those findings implicated that the dominant side might be task specific, moreover, the mechanism of the injury may be specific to the type of sports.⁸⁵ Therefore, both sport and task specific prophylactic neuromuscular training might be effective to reduce the side-to-side disparities, which ultimately may result in decreasing the risk of the injury.⁸⁵

Trunk dominance is characterized by the dysfunctional control of the trunk in the three dimensional space, particularly observed among female athletes during puberty.⁶³ As females grow their height in puberty, they also increase proportion of adipose tissue; whereas, males develop their muscular tissue proportion during the maturation. After the growth spurt, females have higher center of mass (COM) with increased body mass – not muscle mass but rather adipose mass --, especially at the trunk. The disproportional muscle mass, against the increased whole body mass, leads to decreased neuromuscular control of balance. The ground reaction force is substantially affect by the mass of the trunk segment, since it occupies 35.5% of the entire body mass.⁸⁶ Thereby, females are prone to have excessive trunk motion which increases the risk of ACL injury.³² The importance of trunk position is also explained by the relationship with the COM as well as ankle dorsiflexion. When attempting to land with less sagittal trunk flexion, which creates more erect posture and the center of mass (COM) locates posterior to the base of support (BOS), leads to the foot contacting on the ground with reduced ankle dorsiflexion. This results in increasing the GRF and augmenting both quadriceps muscles and trunk flexors contraction to recoup the unstable posture, which ultimately magnifies the anterior tibial shear force that loads the ACL.^{87,88} Prophylactic training program that emphasizes the core stability and proprioceptive controls have shown favorable outcomes,⁸⁹⁻⁹² which verifies the significance of the dynamic balance control that would prevent individuals from sustaining ACL injury and enhance their performance.

In addition to the four different neuromuscular imbalances, the level of hamstring stiffness is also considered a modifiable risk factor. Stiffness is defined as the ratio of change in force to change in length of musculotendinous unit ($k = \Delta \text{force} / \Delta \text{length}$).⁹³ Excessive anterior tibial translation (ATT), as discussed in the MOI section, can place a substantial stress on ACL

and elevate the risk of suffering ACL injury up to four-fold.⁹⁴⁻⁹⁶ Not only the ACL but also the hamstrings are lengthened when ATT occurs. The stiffer the hamstrings, the greater the capability of limiting themselves to be lengthened.⁹⁷⁻⁹⁹ Thereby, greater hamstring stiffness minimizes ATT, which results in reducing the load to the ACL.^{100,101}

Hormonal factors, particularly in females, have garnered the attention with regard to the link between the risk of ACL injury and female sex hormone concentration through the menstrual cycle. This topic is still equivocal, however, it is hypothesized that the female sex hormones, estrogen and progesterone, might affect the biomechanical properties of the ACL due to the existence of receptor sites for those hormones.^{102,103} Consensus statement established in 2005 indicated that the ACL injury risk is elevated during the menstrual phase as well as preovulatory phase (both phases are subdivisions of follicular phase), based on the several consistent outcomes of scientific researches.¹² Although, females appeared to be more susceptible to ACL injury during those two menstrual phases as previous studies revealed, due to the methodological flaws and inconsistency between those studies, conclusions upon the menstrual cycle associated with higher risk of ACL injury have not been drawn.¹⁰⁴ Caution is required when interpreting the hormonal factors based on the menstrual cycle.

Few studies were conducted to investigate the effects of climate upon ACL injury risk. It appears that ACL tears occur more frequently during the time period when evaporation rate is high and rainfall is low in Australian Football League.¹⁰⁵ In addition, risk of ACL injury was higher in hot weather in open stadiums compared with cooler weather in American Football.¹⁰⁶ The reason for the difference in the injury rate based on the environmental factor is that the both friction and torsional resistance between shoe-surface and the playing surface increase during the dry climate.^{107,108} Another extrinsic factor that may contribute to ACL injury is

higher friction between the shoe and playing-surface. It is indicated that the increased shoe-surface friction is more likely to lead a foot to be planted and fixed to the surface, which is frequently observed when ACL injury occurs.¹⁰⁹⁻¹¹¹ In terms of indoor sports, it is suggested that the wooden floor, lower friction, is preferred from the view point of reducing the injury risk, as opposed to the artificial surface the higher the shoe-surface friction, the greater the risk of sustaining ACL injury.¹¹¹

Many researches are available for clinicians to understand risk factors, and the knowledge obtained through the studies must be applied at clinical settings to identify those who at elevated risk of suffering ACL injury, Utilizing screening tests assists clinicians with identifying individual risk factors and who are more prone to ACL injury.

Landing Error Scoring System

The increased ACL injury incidence along with the expansion of athletic population, especially female athletes due to the enactment of Title IX in 1972, has led researchers to develop assessment methods, which identify individuals who are potentially high-risk of sustaining an ACL injury.⁵ In addition, the evidence that individuals with a history of ACL injury are more likely to sustain subsequent injury further encouraged investigators to strive for exploring preventative methods.¹¹²⁻¹¹⁴ The rate of the initial incidence is below 1%; whereas, that of sustaining subsequent ACL injury, especially in younger individuals, is considerably higher than the initial -- 6% to 25%.¹¹²⁻¹¹⁴ However, traditional assessment tools, considered gold-standard, are computer-intensive, which are not readily available at many clinical settings. Thus, there has been a need for a practical testing instrument to identify individuals vulnerable

to ACL injury, and introduce them to prevention- training programs, which will reduce injury risk.¹¹⁵⁻¹¹⁸

The Landing Error Scoring System (LESS) is an assessment tool that is less biomechanical equipment-intensive and meets the demand of the hectic clinical settings, allowing clinicians to screen a high-volume of patients and identify high-risk ACL injury individuals who could benefit from preventative training. Currently, there are two types of the LESS: (1) the original LESS, which is required to utilize video cameras, and (2) the LESS-RT (Real Time), which does not require any biomechanical analysis device, but only visual observation.^{27,119} Both original and modified LESS are conducted by having subjects perform a drop-jump from a 30 cm-high box that is set at individually adjusted distance -- 50% of their height away from the landing area --, followed by an immediate vertical jump.^{27,119} Examiners score the technique errors based on a 17-scale (for the LESS), or 10-scale (for the LESS-RT) scoring system. The LESS involves videotape analysis after the 3-trials of jump-landing performance; whereas, the LESS-RT only requires real-time visual observation over 4-trials of the performance. Both assessment means demonstrated not only good reliability, (ICC=.84 for the LESS; ICC range .72-.81 for the LESS-RT), but also precision (SEM [standard error of measure] = .71 for the LESS; SEM range .69-.79 for the LESS-RT).^{27,119}

Scoring items of the LESS are established based on pathomechanical movements that potentially lead to ACL injury.^{15,17,76} These items are largely divided into three sections: (1) lower limb and trunk position, (2) feet position at different moments, and (3) lower extremity and trunk movements at different time periods that correspond to maximum knee flexion or valgus angles. With regard to the original LESS, the first 15 items are equivalent to either 0 or 1

point, and the remaining two items are equivalent to 0, 1, or 2 points. The LESS scores are roughly categorized into four levels, with a maximum 19 points: (a) Excellent, a score less than or equal to 4; (b) Good, a score greater than 4 or less than or equal to 5; (c) Moderate, a score greater than 5 or less than or equal to 6, and (d) Poor, a score greater than 6.

One of the primary features that distinguish the LESS from other assessment tools that is that it analyzes the landing technique in multi-plane – sagittal, frontal, and transverse --, as opposed to single-plane analysis that is implemented by other screening tools that assess landing biomechanics, such as drop-vertical jump, or tuck jump assessment.¹²⁰⁻¹²⁴ The multiplanar assessment is important as the noncontact ACL injury has been deemed to occur with multi-dimensional complex movements, as discussed in the section of mechanisms of the injury.^{20,22,46,84} Other advantages of the LESS are followings: (1) explicit descriptions of scoring items, (2) time-efficient, and (3) administrable for novice examiner. Since scoring each item is dichotomous in nature -- in other words, determining either yes or no based on the presence of movements or limb positions upon jump-landing performance -- examiners can avoid conjecturing. A few items, including, item 1, 9, 10, and 12 (knee flexion angle at initial contact, foot position-toe in and out, and knee flexion displacement, respectively) require raters to speculate motions or stances, for instance, more or less than 30 degrees of knee flexion at initial contact, most of the scoring items are quite clear and enable smooth implementation of the assessment. However, those few items can be closely assessed through video analysis after recording the subject's performance. In addition, a study that investigated the inter-rater reliability of the LESS between experts – defined, in an article, as an athletic trainer with at least fifteen years certification--, and novice raters – who have been certified less than a year --

showed excellent results.¹²⁵ The outcomes of the study demonstrated the reliability of the assessment tool for the novice examiners.

Identified limitations of the LESS includes the following: (1) it requires two cameras to analyze the performance; (2) whether the assessment is applicable to all athletic populations is unknown; (3) the drop-jump landing technique does not involve complex athletic motions, and (4) contradictions between the scores and biomechanical landing technique errors have been shown in recent findings.^{27,126,127} The camcorders requirement can be eliminated, if further research on the LESS-RT, which is solely based on real-time visual-inspection, is undertaken to verify its validity as well as other aspects that need to be investigated.¹¹⁹ Since a study that examined both reliability and validity of the LESS were conducted on incoming freshmen from military academies, applicability of the assessment tool to athletes participating in different sports and levels of competition remains undetermined.²⁷ Most of the ACL injury occurs with multiple joint kinematic and kinetic events taken place in multiple planes during dynamic sport activities, which can produce even greater kinematic and kinetic alterations that a single drop-vertical jump does not.

A study that aimed to probe whether the LESS is able to predict the risk of sustaining ACL injury revealed that the scores of the assessment tool were not associated with the risk of the injury.¹²⁷ The result raised a question – is the drop-jump test a suitable means to identify individuals at high-risk of sustaining a noncontact ACL injury? Unlike other assessment tools, such as, cross-cutting or side-cutting, the drop-jump does not require complicated athletic skills to complete the task. The inconsistency between the biomechanical errors upon landing technique and the current research finding is that, though, the several variables, including, the

decreased hip and knee flexion, increased valgus and internal rotation moments, and increased anterior tibial shear force were all related to low scores of the LESS, the recent laboratory study demonstrated that anterior tibial translation, valgus and varus, or internal and external rotation were not augmented with decreased knee flexion as well as increased ground-reaction force.^{27,125,126} Those findings promise extensive researches pertaining to the kinematic and kinetic variables that potentially cause ACL injury, and revision of the variables composed of the LESS exam.

Laboratory Assessment and Real-World Performance

As implicated, the laboratory exam exploring jump-landing techniques appear to pose a question on its validity. The LESS is a simple and time-efficient screening tool, which makes it more realistic to implement a preventative assessment at a high-volume patient clinical setting, however, it is a laboratory based test which assesses a single motion, rather than a dynamic and complex movement that may occur during actual sports participation.^{17,18} Laboratory studies based on sidestep cutting that incorporate a mock a defender to mimic a real-world basketball game demonstrated different sidestep cutting maneuvers with the presence of the simulated defender from the motions without the defender.^{128,129} Specifically, increased medial GRF, and greater frontal angles -- hip abduction¹²⁸ and knee valgus^{128,129} -- were observed with the defender present condition. Moreover, a study integrated a ball so as to simulate actual basketball game scenarios showed that sidestep cutting with dribbling imposed greater knee abduction angle during the earlier stance phase.^{129,130} The increased angle of knee abduction has been identified as one of the primary indicators of ACL injury.^{33,64,131,132} Interestingly, sidestep

cutting while dribbling showed increased knee flexion compared to without dribbling (mean with dribbling = 40.18 °; without dribbling = 34.54 °).¹³⁰ Greater knee flexion at the initial contact is commonly deemed as a preferred technique when performing athletic tasks associated with the injury – cutting, landing, and pivoting --, since it hinders the quadriceps muscles from being excessively activated to increase anterior tibial shear force to strain the ACL.^{29,52,67} In contrast, the latest study assimilating both a mock defender and a ball revealed that sidestep cutting was performed with decreased knee flexion (mean = 20.9 °).¹²⁹ The different findings might be explained by the methodological variation between these studies. In previous study, shaper sidestep cutting, 45 degrees, with dribbling was performed¹³⁰; on the other hand, in the recent study, the cutting was conducted with more gentle angle, approximately 33 degrees, as the participants received a pass right before making a cut in front of the static mock defense.¹²⁹

A majority of ACL injury among team sports occur when an offense player possesses the ball during the game situations.³⁰ Typically, an opponent player is present within close distance when an ACL injury occurs.^{18,30} The drop-jump performed in the LESS might miss identifying those athletes who may demonstrate different joint kinematics under game circumstances. During actual competition, unanticipated athletic maneuvers are required as opposed to a controlled environment. An assessment method that analyzes real-time athletic tasks associated with high risk of sustaining ACL injury is needed. Especially, the task pertaining to landing will be the potential research area, since limited research is currently available and it is a common mechanism of the injury.

Conclusions

An array of research have been implemented upon preventing ACL injury for decades, however, this devastating injury is still quite in common among the young active individuals. Screening tools that possibly identify those at the higher risk of sustaining ACL injury and are practical in various clinical settings should be developed and be utilized as a routine, in order to reduce the incidence. Preventative assessment tools, such as, the LESS, would be quite feasible to implement in a clinical setting -- where the budget, time, and space are usually limited -- due to its simplicity of the design. In school environment, especially at college level, majority of the schools have athletic trainers who have acquired motion observational skills through their experience of working with sport teams. Adopting an ACL injury screening method alike the LESS at a school clinical setting where athletic trainers are available would greatly contribute to reducing the number of athletes who sustain of the devastating injury. Prevention of ACL injury cannot be too strongly emphasized, because the injury rate of the subsequent incidence is way greater than the initial event. One way to decrease the occurrence of the injury in a school circumstance can be to introduce the preventative training programs to all athletes who participate in sports that typically involve hazardous movements associated with ACL injury, such as, basketball, soccer, football, and so forth. However, given that there is a screening means to identify those who are at the higher risk of suffering ACL injury, it will be possible to focus clinicians' attention on the limited number of individuals and far more efficiently initiate the prophylactic training programs. Investigation of screening tools for ACL injury is currently ongoing. Limitations that were indicated on laboratory assessment methods, which exam an uncomplicated motion that is less relevant to the actual athletic performance, left open the possibility that assessment methods that involve dynamic athletic tasks may better identify

individuals subject to ACL injury. This will ultimately lead to maintain athletes healthy, and allow them to compete in the sport with enhanced performance through preventative interventions.

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APPENDIX C

TABLES

[Table 1] Mean Values for Participants' Demographics

	Mean \pm SD (range)
Age	20.96 \pm 1.70 (18 - 24)
Height (cm)	166.07 \pm 9.10 (152.4 - 185.9)
Weight (kg)	68.54 \pm 12.17 (52.1 - 108.9)
Years of Basketball Experience	8.76 \pm 4.28 (2 -18)

[Table 2] Inter- and Intra-Rater Reliability of the LESS Scores

Landing Task	Inter-Rater (ICCs)
DVJ	0.99
JS	0.99
RB	0.97

Landing Task	Intra-Rater (ICCs)
DVJ	0.99
JS	1.00
RB	0.96

[Table 3] Inter- and Intra-Rater Reliability of Dartfish
Inter-Rater Intraclass Coefficients (ICCs)

Landing	KFL angle		KAB angle	
Task	IC	Max	IC	Max
DVJ	0.84	0.97	0.99	0.99
JS	0.91	0.97	0.98	0.98
RB	0.89	0.99	0.96	0.99

Intra-Rater Intraclass Coefficients (ICCs)

Landing	KFL angle		KAB angle	
Task	IC	Max	IC	Max
DVJ	0.97	0.99	0.96	0.83
JS	0.96	0.99	0.94	0.98
RB	0.89	0.96	0.97	0.99

[Table 4] Scores for DVJ, JS, and RB Landing Tasks

Landing Task	Mean \pm SD (range)	F value	<i>P</i> value
DVJ	5.97 \pm 1.43 (3.33 - 9.00)	53.936	< 0.001*
JS	8.75 \pm 0.94 (7.00 - 11.00)	53.936	< 0.001*
RB	7.33 \pm 1.02 (4.33 - 9.00)	53.936	< 0.001*

*. Mean LESS scores between each landing task (DVJ vs JS, DVJ vs RB, and JS vs RB) were significantly different.

[Table 5] Simple Contrast Results of Knee Kinematics

Knee Kinematics	Landing Task	<i>P</i> value
KFL at IC	DVJ vs JS	0.370
	DVJ vs RB	0.112
	JS vs RB	0.005*
KFL at Max	DVJ vs JS	0.000*
	DVJ vs RB	0.000*
	JS vs RB	1.000
KAB at IC	DVJ vs JS	0.000*
	DVJ vs RB	0.767
	JS vs RB	0.005*
KAB at Max	DVJ vs JS	0.100
	DVJ vs RB	1.000
	JS vs RB	0.229

*The mean difference is significant at the 0.05 level

[Table 6] Effect Size (ES) for the LESS Scores and Knee Angles

LESS Scores	ES
DVJ vs JS	1.94
DVJ vs RB	0.95
JS vs RB	1.45

KFL IC	ES
JS vs RB	0.95

KFL Max	ES
DVJ vs JS	0.58
DVJ vs RB	0.52

KAB IC	ES
DVJ vs JS	1.15
JS vs RB	0.81

[Table 7] Knee Flexion (KFL) Angles at Initial Contact (IC) and at Maximum Knee Flexion (Max)

Landing Task	KFL IC Mean \pm SD (range)	<i>P</i> value
DVJ	23.37 \pm 6.12 (5.53 - 34.87)	< 0.005*
JS	25.62 \pm 4.80 (14.57 - 35.93)	
RB	21.06 \pm 4.84 (12.10 - 29.97)	

Landing Task	KFL Max Mean \pm SD (range)	<i>P</i> value
DVJ	89.55 \pm 12.14 (68.77 - 115.13)	< 0.001**
JS	82.54 \pm 10.60 (61.80 - 101.03)	
RB	83.22 \pm 11.12 (60.33 - 103.93)	

*. Mean KFL angle at IC between JS and RB was significantly different.

**. Mean KFL angle at Max between DVJ and JS, and DVJ and RB were significantly different

[Table 8] Knee Abduction (KAB) Angles at Initial Contact (IC) and at Maximum Knee Flexion (Max)

Landing Task	KAB IC Mean \pm SD (range)	<i>P</i> value
DVJ	1.94 \pm 3.22 (-3.87 - 6.63)	< 0.001*
JS	5.96 \pm 3.85 (-0.13 - 17.23)	<0.005**
RB	3.10 \pm 3.26 (-1.90 - 10.53)	

Landing Task	KAB Max Mean \pm SD (range)	<i>P</i> value
DVJ	8.79 \pm 7.62 (-9.97 -18.63)	—
JS	11.89 \pm 6.19 (-5.13 - 21.87)	—
RB	9.20 \pm 7.16 (-4.73 - 21.23)	—

*. Mean KAB angle at IC between DVJ and JS was significantly different.

**. Mean KAB angle at IC between JS and RB was significantly different

[Table 9] LESS Items and Percentage of Participants Scoring Erroneous Landing Technique (n=25)

LESS Item	Error Condition	LESS Score	DVJ	% JS	RB
1 Knee flexion angle at initial contact	No	Y=0 N=1	92	80	100
2 Hip flexion angle at initial contact	No	Y=0 N=1	0	0	0
3 Trunk flexion angle at initial contact	No	Y=0 N=1	8	68	76
4 Ankle plantarflexion angle at initial contact	No	Y=0 N=1	16	72	8
5 Knee valgus angle at initial contact	Yes	Y=1 N=0	92	96	96
6 Lateral trunk flexion angle at initial contact	Yes	Y=1 N=0	48	48	60
7 Stance width – Wide	Yes	Y=1 N=0	36	52	76
8 Stance width – Narrow	Yes	Y=1 N=0	24	20	4
9 Foot position – Toe In	Yes	Y=1 N=0	0	0	0
10 Foot position – Toe Out	Yes	Y=1 N=0	0	0	0
11 Symmetric initial foot contact	No	Y=0 N=1	12	44	24
12 Knee flexion displacement	No	Y=0 N=1	4	8	0
13 Hip flexion at max knee flexion	No	Y=0 N=1	0	0	0
14 Trunk flexion at max knee flexion	No	Y=0 N=1	20	68	4
15 Knee valgus displacement	Yes	Y=1 N=0	88	96	92
16 Joint displacement	Average or Stiff (double Penalty for Stiff)	Soft=0 Avg=1 Stiff=2	56	96	88
17 Overall impression	Average or Poor (double penalty for Poor)	Ex=0 Avg=1 Poor=2	88	100	100

FIGURES

[Figure 1] LESS Item Scoring

LESS Item	Operational Definition	Camera View	Error Condition	LESS Score
1 Knee flexion angle at initial contact	At the time point of initial contact, if the knee of the test leg is flexed more than 30 degrees, score YES. If the knee is not flexed more than 30 degrees, score NO.	Side	No	Y=0 N=1
2 Hip flexion angle at initial contact	At the time point of initial contact, if the thigh of the test leg is in line with the trunk then the hips are not flexed and score NO. If the thigh of the test leg is flexed on the trunk, score YES.	Side	No	Y=0 N=1
3 Trunk flexion angle at initial contact	At the time point of initial contact, if the trunk is vertical or extended on the hips, score NO. If the trunk is flexed on the hips, score YES.	Side	No	Y=0 N=1
4 Ankle plantarflexion angle at initial contact	If the foot of the test leg lands toe to heel, score YES. If the foot of the test leg lands heel to toe or with a flat foot, score NO.	Side	No	Y=0 N=1
5 Knee valgus angle at initial contact	At the time point of initial contact, draw a line straight down from the center of the patella. If the line goes through the midfoot, score NO. If the line is medial to the midfoot, score YES.	Front	Yes	Y=1 N=0
6 Lateral trunk flexion angle at initial contact	At the time point of initial contact, if the midline of the trunk is flexed to the left or the right side of the body, score YES. If the trunk is not flexed to the left or right side of the body, score NO.	Front	Yes	Y=1 N=0
7 Stance width – Wide	Once the entire foot is in contact with the ground, draw a line down from the tip of the shoulders. If the line on the side of the test leg is inside the foot of the test leg then score greater than shoulder width (wide), and score YES. If the test foot is internally or externally rotated, grade the stance width based on heel placement.	Front	Yes	Y=1 N=0
8 Stance width – Narrow	Once the entire foot is in contact with the ground, draw a line down from the tip of the shoulders. If the line on the side of the test leg is outside of the foot then score less than shoulder width (narrow), score YES. If the test foot is internally or externally rotated, grade the stance width based on heel placement.	Front	Yes	Y=1 N=0
9 Foot position – Toe In	If the foot of the test leg is internally rotated more than 30 degrees between the time period of initial contact and max knee flexion, then score YES. If the foot is not internally rotated more than 30 degrees between the time period of initial contact to max knee flexion, score NO.	Front	Yes	Y=1 N=0
10 Foot position – Toe Out	If the foot of the test leg is externally rotated more than 30 degrees between the time period of initial contact and max knee flexion, then score YES. If the foot is not externally rotated more than 30 degrees between the time period of initial contact to max knee flexion, score NO.	Front	Yes	Y=1 N=0

11 Symmetric initial foot contact	If one foot lands before the other or if one foot lands heel to toe and the other lands toe to heel, score NO. If the feet land symmetrically, score YES.	Front	No	Y=0 N=1
12 Knee flexion displacement	If the knee of the test leg flexes 45 degrees more than the angle at the position of initial contact to max knee flexion, score YES. If the knee of the test leg does not flex more than 45 degrees, score NO.	Side	No	Y=0 N=1
13 Hip flexion at max knee flexion	If the thigh of the test leg flexes more on the trunk from initial contact to max knee flexion angle, score YES. If the thigh does not flex more on the trunk, score NO.	Side	No	Y=0 N=1
14 Trunk flexion at max knee flexion	If the trunk flexes more from the point of initial contact to max knee flexion, score YES. If the trunk does not flex more, score NO.	Side	No	Y=0 N=1
15 Knee valgus displacement	At the point of max knee valgus on the test leg, draw a line straight down from the center of the patella. If the line runs through the great toe or is medial to the great toe, score YES. If the line is lateral to the great toe, score NO.	Front	Yes	Y=1 N=0
16 Joint displacement	Watch the sagittal plan motion at the hips and knees from initial contact to max knee flexion angle. If the subject goes through large displacement of the trunk, hips, and knees then score SOFT. If the subject goes through some trunk, hip, and knee displacement, but not a large amount, score AVERAGE. If the subject goes through very little, if any trunk, hip, and knee displacement, score STIFF.	Side	Average or Stiff (double Penalty for Stiff)	Soft=0 Avg=1 Stiff=2
17 Overall impression	Score EXCELLENT if the subject displays a soft landing and no frontal plane motion at the knee. Score POOR if the subject displays a stiff landing and large frontal plane motion at the knee. All other landings, score AVERAGE.	Front	Average or Poor (double penalty for Poor)	Ex=0 Avg=1 Poor=2

[Figure 2] Health History/ Basketball Experience Questionnaire

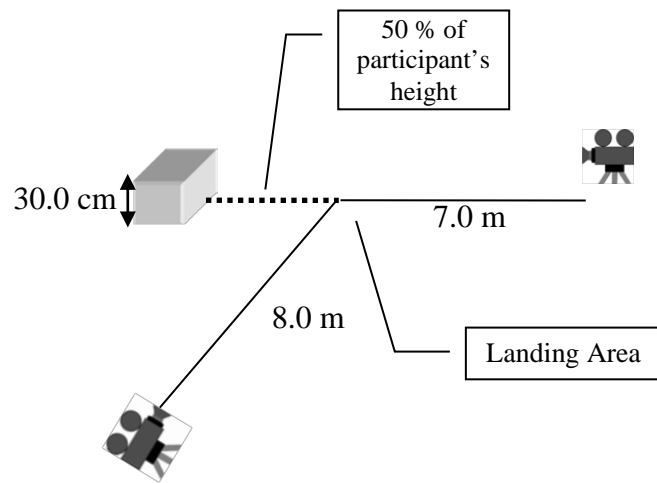
Participant's Name _____ ID: _____

Please circle the answer that best applies to you			
1	Have a history of ACL injury	YES	NO
2	Have other lower extremity injuries resulted in chronic instability at the ankle, knee, and hip joint	YES	NO
3	Have lower back injuries currently	YES	NO
4	Have any medical or neurological conditions that affect landing performance		
5	Have ever engaged in in training program that enhance landing techniques, such as, ACL injury preventative training programs.	YES	NO

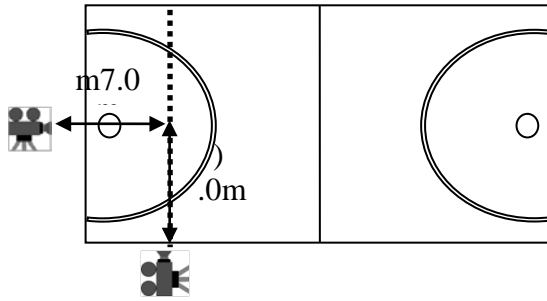
Please circle the answer that best applies to you or indicate your best answer by filling out the blank		
1	Years of basketball experience	_____ years
2	Year you started playing basketball	Since High School Freshman year ____ Junior year ____ Senior year ____ Others _____
3	Competitive level (before college)	School Team or Recreational Team
4	Recreational basketball experience at college	Since college Freshman year ____ Sophomore year ____ Junior year ____ Senior year ____ Others _____

1	Age	_____ year-old
2	Height	_____ cm (_____ ft)
3	Weight	_____ kg (_____ lb)

[Figure 3] Camera Setup for the LESS



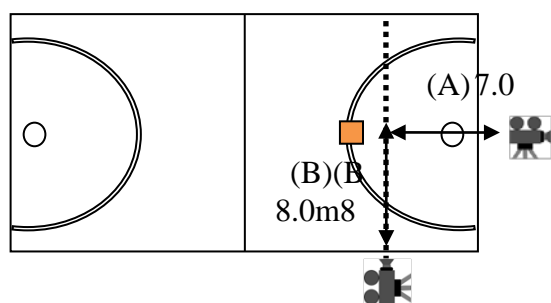
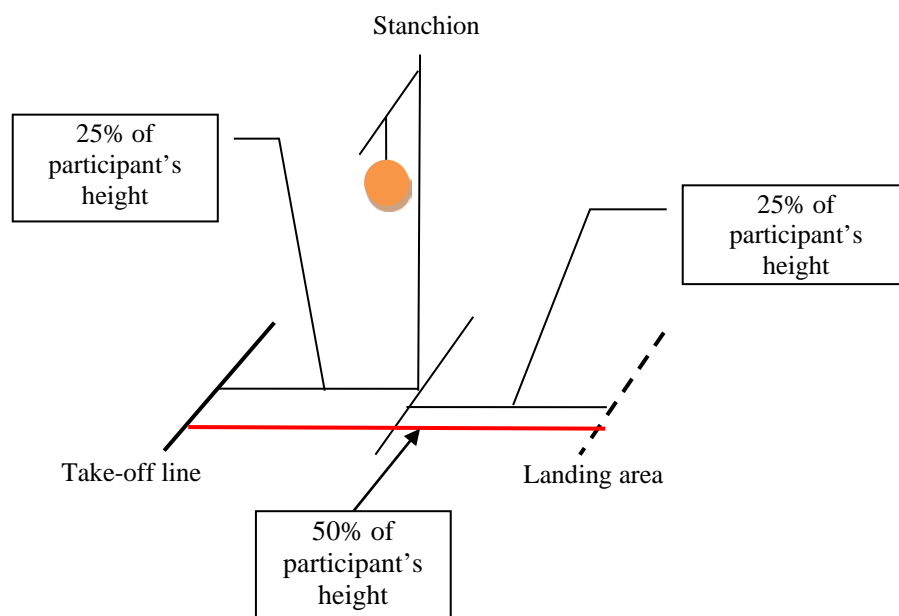
[Figure 4] Camera Setup for Basketball Landing Assessment – Jump-Stop Jump-Shot



lineA= from the frontal camera to free-throw

lineB= from the sagittal camera to center of free-

[Figure 5] Camera Settings for Basketball Landing Assessment – Rebounding

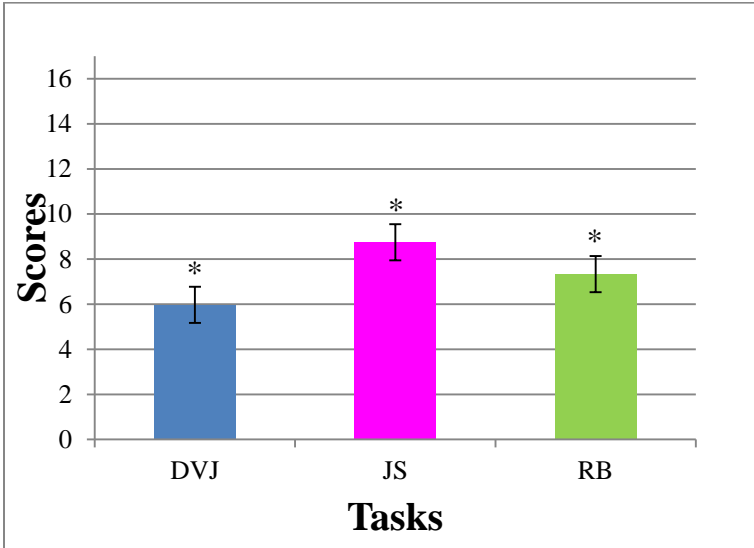


■ = stanchion

A = from the frontal camera to free-throw

B = from the sagittal camera to center of free-throw

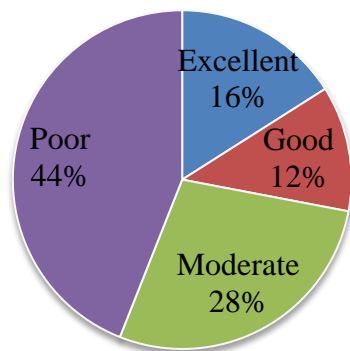
[Figure 6] LESS Scores for DVJ, JS, and RB



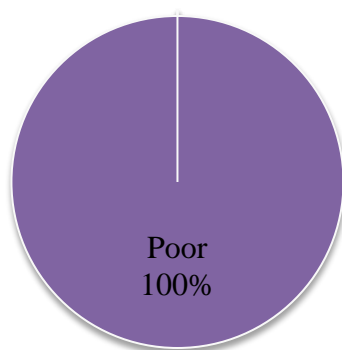
*. Mean LESS score between DVJ and JS, DVJ and RB, and JS and RB were significantly different.

[Figure 7] LESS Landing Technique Categorization

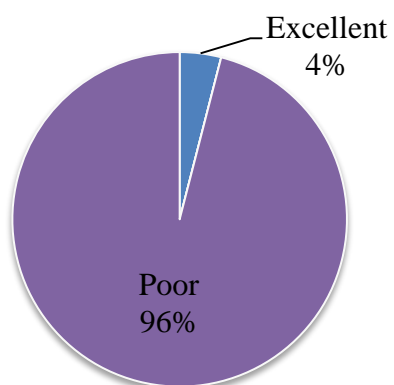
DVJ



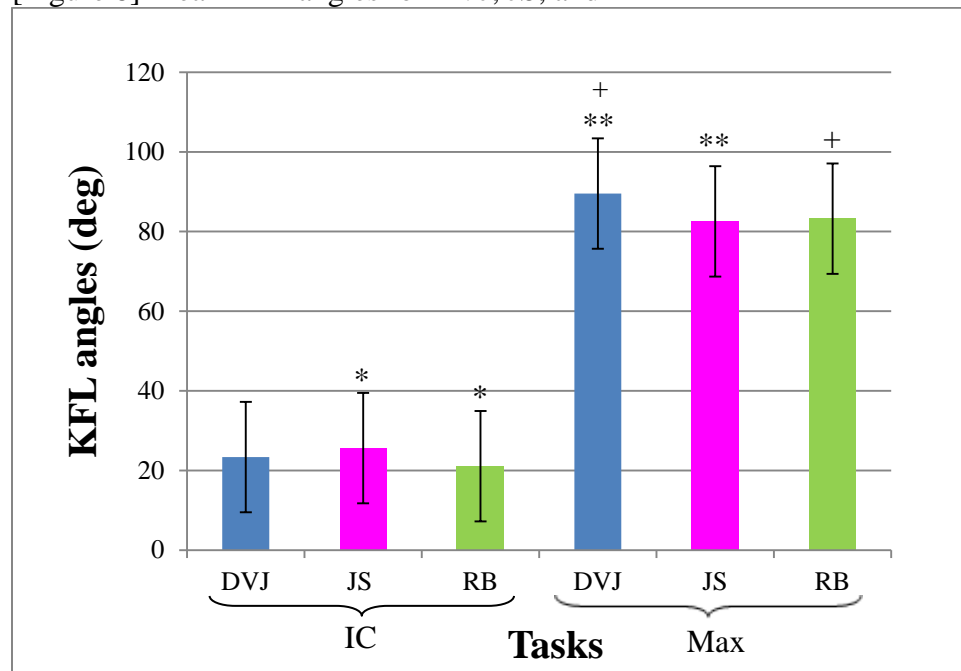
JS



RB

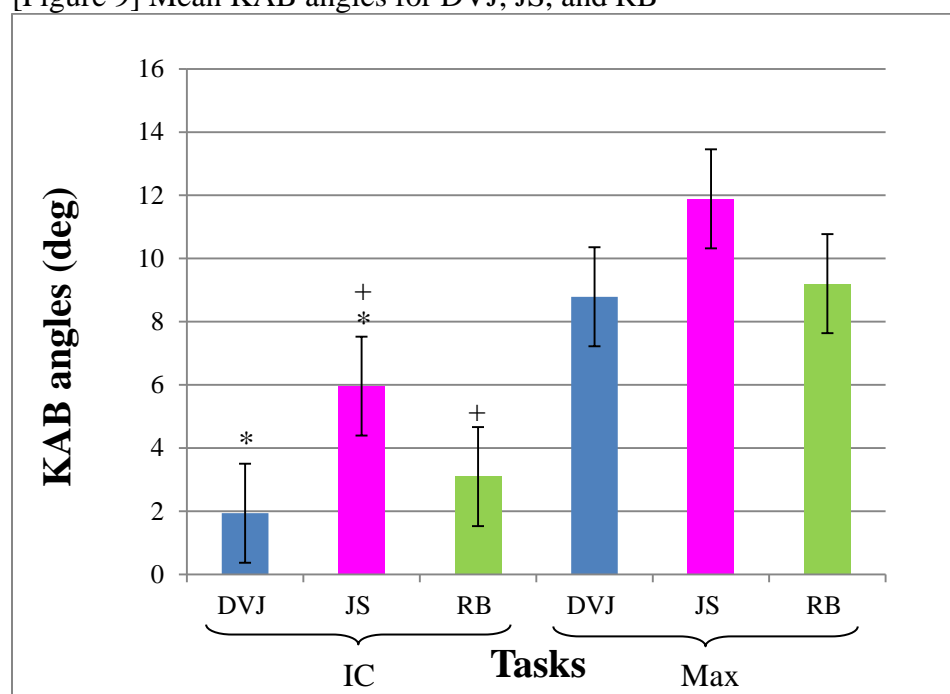


[Figure 8] Mean KFL angles for DVJ, JS, and RB



- *. Mean KFL angle at IC between JS and RB was significantly different.
- **. Mean KFL angle at Max between DVJ and JS was significantly different.
- +. Mean KFL angle at Max between DVJ and RB was significantly different.

[Figure 9] Mean KAB angles for DVJ, JS, and RB



*. Mean KAB angles at IC between DVJ and JS was significantly different.

+. Mean KAB angles at IC between JS and RB was significantly different.

Research Compliance Combined Cover Page

Georgia Southern University

Application for Research Approval

Investigator Information:		
Name of Principal Investigator: Hiromi Kowata	Phone: 304-910-6250	For Office Use Only: Protocol ID: _____ Date Received: _____
Email: hk00725@georgiasouthern.edu (Note: Georgia southern email addresses will be used for correspondence.)	<input type="checkbox"/> Faculty; <input type="checkbox"/> Doctoral; <input type="checkbox"/> Specialist; <input checked="" type="checkbox"/> Masters <input type="checkbox"/> Undergraduate	
Department Name and PO Box: Health and Kinesiology, 30460		
Name(s) of Co-Investigators: Dr. Barry Munkasy Dr. Thomas Buckley Dr. Barry Joyner	Phone: (912) 478 - 0985 (912) 478 - 5268 (912) 478 - 0200	
Email addresses: BMunkasy@Georgiasouthern.edu TBuckley@Georgiasouthern.edu Joyner@Georgiasouthern.edu	<input checked="" type="checkbox"/> Faculty; <input type="checkbox"/> Doctoral; <input type="checkbox"/> Specialist; <input type="checkbox"/> Masters <input type="checkbox"/> Undergraduate (If multiple: identify by initial letter behind name. E.g., F for faculty)	
Department Name and PO Box: Health & Kinesiology, 8076		
Personnel and/or Institutions Outside of Georgia Southern University involved in this research (Attach training certification):		
Project Information: (Note: funded project titles must match grant title)		
Title: Landing Technique Assessment Utilizing Laboratory-Based Landing And Simulated Basketball Landing Tasks		
Brief (less than 50 words) Project Summary: The study aims to compare laboratory-based landing performance with simulated basketball landing performance in order to assess the efficacy of the currently available screening tool.		
Compliance Information:		
Please indicate which of the following will be used in your research: (application may be submitted simultaneously)		
<input checked="" type="checkbox"/> Human Subjects (Complete Section A: Human Subjects below) <input type="checkbox"/> Care and Use of Vertebrate Animals (Complete Section B: Care and Use of Vertebrate Animals below) <input type="checkbox"/> Biohazards (Complete Section C: Biohazards below)		
<input type="checkbox"/> Do you or any investigator on this project have a financial interest in the subjects, study outcome or project sponsor. (A disclosed conflict of interest will not preclude approval. An undisclosed conflict of interest will result in disciplinary action.).		
Project Start Date: 11/20/13 End Date: 5/8/14 (no more than 1 year) Anticipated renewals <input type="checkbox"/> year 2 <input type="checkbox"/> year 3	Check one: <input checked="" type="checkbox"/> New submission <input type="checkbox"/> Resubmission # _____	
Funding Source: <input type="checkbox"/> Federal <input type="checkbox"/> State <input type="checkbox"/> Private <input type="checkbox"/> Internal GSU <input checked="" type="checkbox"/> Self-funded/non- funded		
Funding Agency: <input type="checkbox"/> Not Applicable		

Section A: Human Subjects ☐ Not Applicable

Number of Subjects (Maximum) 40		Date of IRB education completion: 2/8/13 (attach copy of completion certificate)	
<i>Purpose of Research: (Check all that apply)</i> <input checked="" type="checkbox"/> Publication/use in thesis/dissertation <input checked="" type="checkbox"/> Publication (journal, book, etc.) <input checked="" type="checkbox"/> Poster/presentation to a scientific audience <input type="checkbox"/> Completion of a class project <input type="checkbox"/> Presentation to GSU audience only <input type="checkbox"/> Presentation in outside of GSU <input type="checkbox"/> Results will not be published <input type="checkbox"/> Other		<i>Please indicate if the following are included in the study (Check all that apply):</i> <input checked="" type="checkbox"/> Informed Consent Document <input type="checkbox"/> Greater than minimal risk <input type="checkbox"/> Research Involving Minors <input type="checkbox"/> Deception <input checked="" type="checkbox"/> Generalizable knowledge (results are intended to be published) <input type="checkbox"/> Survey Research <input type="checkbox"/> At Risk Populations (prisoners, children, pregnant women, etc.) <input checked="" type="checkbox"/> Video or Audio Tapes <input checked="" type="checkbox"/> Medical Procedures, including exercise, administering drugs/dietary supplements, and other procedures	
Section B: Care and Use of Vertebrate Animals <input checked="" type="checkbox"/> Not Applicable			
<i>Purpose of use/care of animals:</i> <input type="checkbox"/> Research <input type="checkbox"/> Teaching <input type="checkbox"/> Demo only <input type="checkbox"/> Student participation in faculty work <input type="checkbox"/> Class Project <input type="checkbox"/> Exhibition <input type="checkbox"/> Display		<i>Please indicate if the following are included in the study:</i> <input type="checkbox"/> Physical intervention with vertebrate animals <input type="checkbox"/> Housing of vertebrate animals <input type="checkbox"/> Euthanasia of vertebrate animals <input type="checkbox"/> Use of sedation, analgesia, or anesthesia <input type="checkbox"/> Surgery <input type="checkbox"/> Farm animals for biomedical research (e.g., diseases, organs, etc.) <input type="checkbox"/> Farm animals for agricultural research (e.g., food/fiber production, etc.) <input type="checkbox"/> Observation of vertebrate animals in their natural setting	
Section C: Biological Research <input checked="" type="checkbox"/> Not Applicable <input type="checkbox"/> Submitted Separately			
<i>Biosafety Level:</i> <input type="checkbox"/> Exempt <input type="checkbox"/> BSL 1 <input type="checkbox"/> BSL 2 <input type="checkbox"/> BSL 3		<i>Please indicate if the following are included in the study:</i> <input type="checkbox"/> Use of rDNA <input type="checkbox"/> Non native/invasive plant species <input type="checkbox"/> Last EHS lab safety inspection date: <u>Attach Report</u> <input type="checkbox"/> Last IBC biosafety lab inspection date: <u>Attach Report</u>	
Signature of Applicant(s): (PI, CoPI)		Date:	
X			
If student project please complete research advisor's information below (note that advisor signature must be received before application will be reviewed.):			
Research Advisor's Name: Dr. Barry Munkasy		Advisor's E-mail: BMunkasy@Georgiasouthern.edu	
Advisor's Phone: (912) 478 – 0985		Advisor's Department: Health & Kinesiology P.O. Box: 8076	
If student project - Signature of faculty member who is responsible for the student conducting research. If faculty project – Signature of department head or chair.			
By signing this cover page I acknowledge that I have reviewed and approved this protocol for scientific merit, rational and significance. I further acknowledge that I approve the ethical basis for the study.			
Signature of Committee Chair/Research Advisor (if student) Department Chair(if faculty):		Date:	
X			

CERTIFICATION OF INVESTIGATOR RESPONSIBILITIES

By signing below I agree/certify that:

1. I have reviewed this protocol submission in its entirety and I state that I am fully cognizant of, and in agreement with, all submitted statements and that all statements are truthful.
2. This application, if funded by an extramural source, accurately reflects all procedures involving human participants described in the proposal to the funding agency previously noted.
3. I will conduct this research study in strict accordance with all submitted statements except where a change may be necessary to eliminate an apparent immediate hazard to a given research subject.
 - a. I will notify the IRB promptly of any change in the research procedures necessitated in the interest of the safety of a given research subject.
 - b. I will request and obtain IRB approval of any proposed modification to the research protocol or informed consent document(s) prior to implementing such modifications.
4. I will ensure that all co-investigators, and other personnel assisting in the conduct of this research study have been provided a copy of the entire current version of the research protocol and are fully informed of the current (a) study procedures (including procedure modifications); (b) informed consent requirements and process; (c) anonymity and/or confidentiality assurances promised when securing informed consent (d) potential risks associated with the study participation and the steps to be taken to prevent or minimize these potential risks; (e) adverse event reporting requirements; (f) data and record-keeping requirements; and (g) the current IRB approval status of the research study.
5. I will not enroll any individual into this research study: (a) until such time that the conduct of the study has been approved in writing by the IRB; (b) during any period wherein IRB renewal approval of this research study has lapsed; (c) during any period wherein IRB approval of the research study or research study enrollment has been suspended, or wherein the sponsor has suspended research study enrollment; or (d) following termination of IRB approval of the research study or following sponsor/principal investigator termination of research study enrollment.
6. I will respond promptly to all requests for information or materials solicited by the IRB or IRB Office.
7. I will submit the research study in a timely manner for IRB renewal approval.

8. I will not enroll any individual into this research study until such time that I obtain his/her written informed consent, or, if applicable, the written informed consent of his/her authorized representative (i.e., unless the IRB has granted a waiver of the requirement to obtain written informed consent).
9. I will employ and oversee an informed consent process that ensures that potential research subjects understand fully the purpose of the research study, the nature of the research procedures they are being asked to undergo, the potential risks of these research procedures, and their rights as a research study volunteer.
10. I will ensure that research subjects are kept fully informed of any new information that may affect their willingness to continue to participate in the research study.
11. I will maintain adequate, current, and accurate records of research data, outcomes, and adverse events to permit an ongoing assessment of the risks/benefit ratio of research study participation.
12. I am cognizant of, and will comply with, current federal regulations and IRB requirements governing human subject research including adverse event reporting requirements.
13. I will notify the IRB within 24 hours regarding any unexpected study results or adverse events that injure or cause harm to human participants.
14. I will make a reasonable effort to ensure that subjects who have suffered an adverse event associated with research participation receive adequate care to correct or alleviate the consequences of the adverse event to the extent possible.
15. I will notify the IRB prior to any change made to this protocol or consent form (if applicable).
16. I will notify the IRB office within 30 days of a change in the PI or the closure of the study.

Principal Investigator Name (typed)

Principal Investigator Signature Date

Faculty Advisor Name (typed)

Faculty Advisor Signature* Date

***Faculty signature indicates that he/she has reviewed the application and attests to its completeness and accuracy**

GSU INFORMED CONSENT



COLLEGE OF HEALTH & HUMAN SCIENCES

DEPARTMENT OF HEALTH & KINESIOLOGY

Title of Project : An Anterior Cruciate Ligament Injury Landing Technique Assessment Utilizing Laboratory-Based Landing And Simulated Basketball Landing Tasks

Investigator's Name: Hiromi Kowata, ATC, LAT Phone: (304) 910 - 6250

Participant's Name

Date: _____

Data Collection Location: Recreational Activity Center, Georgia Southern University Campus

1. The purpose of this research is to compare the differences in landing technique scores, based on Landing Error Scoring System (LESS), between laboratory-based drop-vertical jump, and simulated basketball landing tasks; jump-stop jump-shot, and rebounding. The results of this study may indicate the need for a new assessment tool that is more oriented to the real-world basketball performance.
2. If you agree to participate in this study, you will be asked to perform three trials of the Landing Error Scoring System (LESS) test, and three trials of two different basketball landing tasks. The LESS is an anterior cruciate ligament (ACL) injury screening tool involving a drop-vertical jump. Basketball landing tasks consist of jump-stop jump shot and rebounding will be performed for three trials, respectively.
3. There is minimal risk associated with participating in this study. Although, you could fall and injure yourself during the landing technique assessments, all performance will be assessed in the basketball court where only participants and the lead researcher are allowed to access, relatively safe and controlled environment, which will minimize risks arisen from the landing tasks. You understand that medical care is available in the event of injury resulting from research but that neither financial compensation nor free medical treatment is provided. You also understand that you are not waiving any rights that you may have against the University for injury resulting from negligence of the University or investigators. Should medical care be required, you may contact Health Services at (912) 478 – 5641.
4. You will likely receive no direct benefit for participating in this study, however you will be provided your results, if you so request. The results of this study may be used to better treat individuals who are at higher risk of sustaining ACL injury.

5. You will attend one testing session lasting approximately 30 minutes. You will be videotaped and all recording will remain on a password protected computer and stored for the duration of the study and at least 7 years as required by the Board of Regents.
6. You understand that all data concerning myself will be kept confidential and available only upon my written request to Hiromi Kowata, B.S. You understand that any information about my records will be handled in a confidential (private) manner consistent with medical records.
7. If you have any questions about this research project, you may call Hiromi Kowata at (304) 910-6250 or email (hk00725@georgiasouthern.edu). If you have any questions or concerns about your rights as a research participant in this study it should be directed to the IRB Coordinator at the Office of Research Services and Sponsored Programs at (912) 478-0843 or by email at: IRB@georgiasouthern.edu.
8. As an incentive to participate, ten out of total participants will receive gift-cards worth \$10. Participants will fill out forms with their names and their date of birth to automatically be entered into a drawing for the prize.
9. You understand that you do not have to participate in this project and your decision to participate is purely voluntary. At any time you can choose to end your participation by telling the primary investigator, Hiromi Kowata or any other of the investigators.
10. You understand that you may terminate participation in this study at anytime without prejudice to future care or any possible reimbursement of expenses, compensation, employment status, or course grade, and that owing to the scientific nature of the study, the investigator may in his/her absolute discretion terminate the procedures and/or investigation at any time. Your participation will not affect any grade in any class.
11. You certify you are 18 years of age or older and you have read the preceding information, or it has been read to you, and understand its contents. Any questions you have pertaining to the research have been, and will continue to be, answered by the investigators listed at the beginning of this consent form or at the phone numbers given (304) 910 – 6250.
12. You must be 18 years of age or older to consent to participate in this research study. If you consent to participate in this research study and to the terms above, please sign your name and indicate the date below
You will be given a copy of this consent form to keep for your records. This project has been reviewed and approved by the GSU Institutional Review Board under tracking number _____.



Title of Project: An Anterior Cruciate Ligament Injury Landing Technique Assessment
Utilizing Laboratory-Based Landing And Simulated Basketball Landing Tasks

Principal Investigator

Hiromi Kowata, ATC, LAT
1205 Hanner Building
(304) 910 – 6250
hk00725@georgiasouthern.edu

Other Investigator

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BMunkasy@Georgiasouthern.edu

Faculty Advisor

Thomas Buckley, Ed.D., ATC
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(912) 478 – 5268
TBuckley@Georgiasouthern.edu

Faculty Advisor

Barry Joyner, PhD
2115-A Hollis Building
(912) 478-0200
Joyner@Georgiasouthern.edu

Participant Signature

Date

I, the undersigned, verify that the above informed consent procedure has been followed.

Investigator Signature

Date

GEORGIA SOUTHERN UNIVERSITY INSTITUTIONAL REVIEW BOARD

INSTRUCTIONS FOR PREPARATION OF PROPOSAL NARRATIVE

Instructions: *Please respond to the following as clearly as possible. The Narrative should include a step by step plan of how you will obtain your subjects, conduct the research and analyze the data. Make sure the narrative clearly explains aspects of the methodology that provide protections for your human subjects. Your narrative should be written to be read and understood by a general audience who does not have prior knowledge of your research and by committee members who may not be expert in your specific field of research. Your reviewers will only have the information you provide in your application. Explain any technical terms, jargon or acronyms. The narrative is a part of the complete application.*

The application may be submitted electronically at irb@georgiasouthern.edu (email attachment) or sent to the Office of Research Services and Sponsored Programs, at P. O. Box 8005, Statesboro, GA 30460, fax (912) 478-071.

Personnel. *Please list any individuals who will be participating in the research. Also please detail the experience, level of involvement in the process and the access to information that each may have.*

Hiromi Kowata, B.S., ATC
Barry Munkasy, Ph.D.
Thomas Buckley, Ed.D., ATC
Barry Joyner, Ph.D

Hiromi Kowata will have primary responsibility for subject recruitment, and data collection. Dr. Munkasy and Dr. Buckley will assist Hiromi Kowata with project design and data interpretation and assist with subject recruitment, data collection, and data analysis. Dr. Joyner will primarily assist Hiromi Kowata with the data analysis and statistical analysis. All four members of the research team will have access to all participant information and the NIH and CITI/HIPS training forms are attached for all three members of the research team.

Purpose. *1. Briefly describe in one or two sentences the purpose of your research. 2. What questions are you trying to answer in this experiment? Please include your hypothesis in this section. The jurisdiction of the IRB requires that we ensure the appropriateness of research. It is unethical to put participants at risk without the possibility of sound scientific result. For this reason, you should be very clear about how participants and others will benefit from knowledge gained in this project.*

The purpose of this study will be to compare the differences in LESS scoring between a laboratory based LESS drop-vertical jump, and two simulated basketball landing performances, jump-stop jump-shot and rebounding among female recreational basketball players. It is hypothesized that female recreational basketball players' LESS scores will differ under the three landing conditions. Another purpose of this study will be to compare knee flexion and abduction angles during these tasks. It is hypothesized that knee flexion and abduction angles during these tasks will be different, which may indicate the need for a more applied clinical assessment tool.

Literature Review. *Provide a brief description of how this study fits into the current literature. Have the research procedures been used before? How were similar risks controlled for and documented in the literature? Have your instruments been validated with this audience? Include citations in the description.*

Prevention is of the highest significance in terms of the anterior cruciate ligament (ACL) injury due to the substantial incidence rate, prolonged recovery, increased odds of recurrence, and complications including chronic knee instability, and the potential early onset of osteoarthritis (OA). (Arendt et al, 1999; Gottlob et al, 1999; Pinczewski et al, 2007) Anterior cruciate ligament injuries occur up to over 250,000 annually in the United States, (Hewett et al, 1999; Griffin et al, 2006) with the annual medical costs for both surgery and rehabilitation exceed \$2 billion. (Gottlob et al, 1999) Basketball is one of the most common sports that ACL injuries are frequently reported due to the nature of the sport which involves landing, cutting, and pivoting maneuvers that are highly associated with ACL injury. (Boden et al, 2000; Krosshaug et al, 2007) As those athletic motions illustrated, non-contact ACL injury rate is remarkably high -- as high as 84% of all ACL ruptures. (Boden et al, 2000; Fauno et al, 2006). Landing is the most common mechanism of injury in terms of basketball. Kinetic and kinematic features reported when the incidence occurs include decreased flexion at the knee (less than 30 degrees), increased knee abduction angle combined with internal tibial rotation, which result in increased anterior tibial shear force induced by increased quadriceps contraction with decreased hamstring co-contraction. (Hewett et al, 2005; Chappell et al, 2002; DeMorat et al, 2004) Nevertheless, effective preventative training programs, which include plyometric, balance, and strengthening training, are currently available, the injury rate of this devastating injury has not diminished regardless of gender. (Myer et al, 2006; Granan et al, 2008; Agel et al, 2005). Screening tools based on three-dimensional biomechanical motion analysis are gold-standard to potentially identify individuals with higher risk of sustaining ACL injury, however, installing the costly device and time-consuming analysis process limit its widespread use and large-scale screening. (Myer et al, 2011; Chappell et al, 2007; McLean et al, 2008). Thereby, a practical screening tool that enables clinicians to assess ACL injury risk at a large-scale is in desperate need.

The Landing Error Scoring System (LESS) is a landing technique assessment tool that is less biomechanical equipment-intensive – requiring only two cameras recording frontal and sagittal movement planes. The landing technique is rated based on 17 items considered ACL injury risk factors. (Padua et al, 2009). Though, the LESS is a reliable and simple screening tool, it is a laboratory based test which assess a contrived motion, rather than a dynamic and complex movement that may occur during actual sports participation. The majority of ACL injuries among team sports appear to occur in an offense player possessing a ball under the game situations. (Boden, 2009).

Furthermore, in terms of basketball, players' attentions are on the goal rim, defense players, or the ball being passed, which indicates that their attentions are apart from the motions that their bodies create, such as, landing motion. (Krosshaug, 2007). The drop-vertical jump performed in the laboratory-based assessment might fail to identify those who may demonstrate different joint kinematics with actual basketball landing maneuvers, such as and jump-shot and rebounding, which involve a ball and varied player's attention. (Krosshaug, 2007). Simulated real world performance might be able to elicit kinematics features associated with ACL injury that cannot be observed in laboratory based assessment. This study aims to compare landing performance of the laboratory-based screening test and actual basketball landing maneuvers (jump-stop jump-shot and rebounding).

Outcome. *Please state what results you expect to achieve? Who will benefit from this study? How will the participants benefit (if at all). Remember that the participants do not necessarily have to benefit*

directly. The results of your study may have broadly stated outcomes for a large number of people or society in general.

The participants will not benefit from participation in the study. The potential benefit is to the sports medicine community in the potential development of a more clinically applied assessment technique which is both commonly utilized (i.e., no new training required) and readily available to clinicians. A more applied assessment method may allow future clinicians to identify targeted individuals who are at higher risk of ACL injury and most benefit from preventative training program, which ultimately will reduce the incidence of ACL injury.

Describe your subjects. *Give number of participants, and applicable inclusion or exclusion requirements (ages, gender requirements, etc.).*

We aim to recruit 30 participants to complete the study. The inclusion criteria will consist of current enrollment as a student at Georgia Southern University who is over the age of 18 and under 25 participating in recreational basketball and is open to female participants. The exclusion criteria will include history of an ACL injury, other lower extremity injuries resulted in chronic instability at the ankle, knee, and hip joint, any medical or neurological conditions that affect landing performance, and engaging in training program that enhance landing techniques, such as, ACL injury preventative training programs. (Appendix A)

Recruitment and Incentives: *Describe how subjects will be recruited. (Attach a copy of recruitment emails, flyers or etc.) If provided, describe what incentives will be used and how they will be distributed.)*

Incentives of \$10 gift-cards will be provided to ten participants that will be determined by a raffle. The primary investigator will place flyers at the Recreation Activity Center at Georgia Southern University where recreational basketball athletes will be found in an effort to solicit volunteers.

Research Procedures and Timeline: *Enumerate specifically what will you be doing in this study, what kind of experimental manipulations you will use, what kinds of questions or recording of behavior you will use. Focus on the interactions you will have with the human subjects. (Where applicable, attach a questionnaire, focus group outline, interview question set, etc.) Describe in detail any physical procedures you may be performing.*

The participants will be tested on one occasion and the test session will last approximately 30 minutes, including the explanation of the project, the informed consent process, the health history questionnaire (Appendix C), and the testing process. Following explaining the project and receiving oral and written informed consent, the individual will have their height and weight measured using a standard physician scale. The testing process will consist of performing the LESS, and the two different basketball landing tasks (jump-stop jump-shot and rebounding). The testing order will be randomized.

The LESS (Appendix C, Figure1) will be conducted by having the individual perform a drop-vertical jump from a 30 cm-high box that is set at an individually adjusted distance, 50% of their height away from the landing area followed by an immediate vertical jump. The dominant-limb (which is referred as the preferred kicking leg) will be primarily assessed for the simplicity of the measurement process. An examiner will score the technique errors based on a 17-scale scoring system, followed by the videotape analysis after the 3-trials of jump-landing performance. Scoring items are based on pathomechanical movements that potentially lead to ACL injury. The maximum score per trial is 19. The average of the three test trials will be used for data analysis. A component of basketball landing

task, jump-stop jump-shot, will be examined by having the individual dribble about 5m for three times followed by double-leg stop-jump and taking a jump-shot from the free-throw line. The individual will also be asked to perform rebounding, which will be examined by having the individual perform three trials of rebounding that will be initiated by taking 2 to 3 steps. The individual will be asked to reach a basketball hanging from the stanchion via a rope. Strong ACL injury predictors, the knee flexion angle and knee abduction angle, at the initial contact and maximal knee flexion, will be analyzed. Two standard HDV video camcorders set approximately 7 m from the individual will be utilized to capture both sagittal and frontal views of the movements for all landing technique examinations. Each assessment will take less than 5 minutes to complete. Dartfish ProSuite software will be utilized for the video analysis. The videos will be retained throughout the testing process and will be deleted following data analysis and eventual manuscript submission and acceptance.

Data Analysis: *Briefly describe how you will analyze and report the collected data. Include an explanation of how will the data be maintained after the study is complete and anticipated destruction date or method used to render it anonymous for future use.*

Independent variables for the first purpose of this study will be, the three different landing performance; drop-vertical jump, jump-stop jump shot, and rebounding. Dependent variables that will be analyzed will include the LESS score of the three aforementioned landing performances. Independent variables for the second purpose will also be the three landing performance. Corresponding dependent variables will be knee flexion angle and knee abduction angle at initial contact and maximal knee flexion for each landing skill. Each landing performance will be assessed by applying the LESS scoring protocol. The selected kinematic variables will be examined by reviewing the performance videos and using Dartfish ProSuite software. The video recordings of the LESS drop-vertical jump, and basketball landing performance will be maintained for the duration of the study and retained as the data is analyzed and stored until the eventual manuscript is accepted for publication. Once all aspects of the study are completed and the required 7 years has passed, the digital video files will be deleted and the score sheets will be destroyed. The participants will be identified on the documentation only using an assigned participant ID which not include their name, social security number, or Eagle ID. As the participant will clearly be visible on the video, the video files will be stored, prior to their deletion, on the laboratory computer which is password protected and the laboratory itself has limited key access.

Special Conditions:

Risk. *Is there greater than minimal risk from physical, mental or social discomfort? Describe the risks and the steps taken to minimize them. Justify the risk undertaken by outlining any benefits that might result from the study, both on a participant and societal level. Even minor discomfort in answering questions on a survey may pose some risk to subjects. Carefully consider how the subjects will react and address ANY potential risks. Do not simply state that no risk exists. Carefully examine possible subject reactions. If risk is no greater than risk associated with daily life experiences state risk in these terms.*

There is a minimal risk associated with participation in this study. There is a risk of falling during the LESS test; however, a member of the research team will stay in close proximity to the individual (i.e., “spot”) in the event they begin to fall. Studies that assessed thousands of trials of the LESS did not address any published or anecdotal reports of injury associated with LESS performance. Though, there is a minimal risk of falling when performing basketball jump shot, many studies were conducted to assess the performance with hundreds of trials of jump shot. No injuries associated with jump shot were

reported. Although, rebounding performance possesses a minimal risk of both lower and upper extremity injuries, studies that involve vertical jump (VJ), which has quite similar component of rebounding except for involvement of a ball, have been done without any reports of injuries driven from VJ performance. Vertical jump (VJ) is widely used as a power assessment. Many studies have conducted to illustrate the enhancement of vertical jump height throughout plyometric training programs. Neither lower extremity nor upper extremity injuries derived from (VJ) were reported after the completion of hundreds of VJ trials. A study that incorporated a basketball into a drop-vertical jump (DVJ) assessment to simulate basketball rebound play, which involved hundreds of DVJ and rebound trials, was also safely investigated – no lower extremity or upper extremity injuries were reported. All landing performance will be assessed in the basketball court where only participants and the lead researcher are allowed to access, relatively safe and controlled environment, which will minimize risks arisen from all the landing tasks. These risks are limited in comparison to the potential benefit of developing a new assessment method to better identify individuals with higher risk of ACL injury.

Research involving minors. *Describe how the details of your study will be communicated to parents/guardians. If part of an in-school study (elementary, middle, or high school), describe how permission will be obtained from school officials/teachers, and indicate whether the study will be a part of the normal curriculum/school process. Please provide both parental consent letters and child assent letters (or processes for children too young to read). If not applicable indicate N/A or delete this section.*

There are no minors associated with this study.

Deception. *Describe the deception and how the subject will be debriefed. Briefly address the rationale for using deception. Be sure to review the deception disclaimer language required in the informed consent. **Note:** All research in which active deception will be used is required to be reviewed by the full Institutional Review Board. Passive deception may receive expedited review. If not applicable indicate N/A or delete this section.*

There is no deception associated with this study.

Medical procedures. *Describe your procedures, including safeguards. If appropriate, briefly describe the necessity for employing a medical procedure in this study. Be sure to review the medical disclaimer language required in the informed consent. If not applicable indicate N/A or delete this section.*

There are no medical procedures associated with this study.

Cover page checklist. *Please provide additional information concerning risk elements checked on the cover page and not yet addressed in the narrative. If none, please state "none of the items listed on the cover page checklist apply." The cover page can be accessed from the IRB forms page. (Note – if a student, make sure your advisor has read your application and signed your cover page. (Your advisor is responsible for the research you undertake in the name of GSU.)*

Reminder: No research can be undertaken until your proposal has been approved by the IRB.

Georgia Southern University Office of Research Services & Sponsored Programs		
Institutional Review Board (IRB)		
Phone: 912-478-0843	Veazey Hall 2021	
Fax: 912-478-0719	IRB@GeorgiaSouthern.edu	P.O. Box 8005 Statesboro, GA 30460

To: Hiromi Kowata
Dr. Barry Munkasy
Dr. Thomas Buckley
Dr. Barry Joyner

CC: Charles E. Patterson
Vice President for Research and Dean of the Graduate College

From: Office of Research Services and Sponsored Programs
Administrative Support Office for Research Oversight Committees
(IACUC/IBC/IRB)

Initial Approval Date: 12/17/13

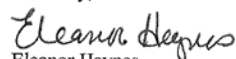
Expiration Date: 11/30/14

Subject: Status of Application for Approval to Utilize Human Subjects in Research –
Expedited Process

After a review of your proposed research project numbered **H14217** and titled "**Landing Technique Assessment Utilizing Laboratory-Based Landing and Simulated Basketball Landing Tasks**" it appears that (1) the research subjects are at minimal risk, (2) appropriate safeguards are planned, and (3) the research activities involve only procedures which are allowable. You are authorized to enroll up to a maximum of 40 subjects.

Therefore, as authorized in the Federal Policy for the Protection of Human Subjects, I am pleased to notify you that the Institutional Review Board has approved your proposed research. – This study aims to compare laboratory-based landing performance with simulated basketball landing performance in order to assess the efficacy of the currently available screening tool.

If at the end of this approval period there have been no changes to the research protocol; you may request an extension of the approval period. Total project approval on this application may not exceed 36 months. If additional time is required, a new application may be submitted for continuing work. In the interim, please provide the IRB with any information concerning any significant adverse event, **whether or not it is believed to be related to the study**, within five working days of the event. In addition, if a change or modification of the approved methodology becomes necessary, you must notify the IRB Coordinator **prior** to initiating any such changes or modifications. At that time, an amended application for IRB approval may be submitted. Upon completion of your data collection, you are required to complete a *Research Study Termination* form to notify the IRB Coordinator, so your file may be closed.

Sincerely,

Eleanor Haynes
Compliance Officer

CITI Collaborative Institutional Training Initiative

Human Subjects-Social & Behavioral Research - Basic/Refresher Curriculum

Completion Report

Printed on 4/22/2013

Learner: Hiromi Kowata (username: hk00725)

Institution: Georgia Southern University

Contact Information

100 Bermuda Run

Apt.A-12

Statesboro, GA, 30458

Department: Health and Kinesiology - Athletic Training

Phone: 3049106250

Email: hk00725@mygeorgiasouthern.edu

Human Subjects-Social & Behavioral Research - Basic/Refresher: Choose this group to satisfy CITI training requirements for Investigators and staff involved primarily in Social/Behavioral Research with human subjects.

Stage 1. Basic Course Passed on 02/08/13 (Ref # 9590574)

Required Modules	Date Completed	
Belmont Report and CITI Course Introduction	02/03/13	2/3 (67%)
Students in Research	02/03/13	9/10 (90%)
History and Ethical Principles - SBR	02/03/13	4/5 (80%)
Defining Research with Human Subjects - SBR	02/04/13	5/5 (100%)
The Regulations and The Social and Behavioral Sciences - SBR	02/04/13	5/5 (100%)
Assessing Risk in Social and Behavioral Sciences - SBR	02/04/13	5/5 (100%)
Informed Consent - SBR	02/06/13	5/5 (100%)
Privacy and Confidentiality - SBR	02/06/13	4/5 (80%)
Conflicts of Interest in Research Involving Human Subjects	02/06/13	4/5 (80%)
Elective Modules	Date Completed	
Cultural Competence in Research	02/08/13	5/5 (100%)

Records-Based Research	02/08/13	1/2 (50%)
Research with Children - SBR	02/08/13	2/4 (50%)
International Research - SBR	02/08/13	3/3 (100%)

1) For this Completion Report to be valid, the learner listed above must be affiliated with a CITI participating institution. Falsified information and unauthorized use of the CITI course site is unethical, and may be considered scientific misconduct by your institution.

2) Paul Braunschweiler Ph.D.
Professor, University of Miami
Director Office of Research Education
CITI Course Coordinator

CITI Collaborative Institutional Training Initiative

CITI Health Information Privacy and Security (HIPS) Curriculum Completion Report

Printed on 4/22/2013

Learner: Hiromi Kowata (username: hk00725)

Institution: Georgia Southern University

Contact Information 100 Bermuda Run
Apt.A-12
Statesboro, GA, 30458
Department: Health and Kinesiology - Athletic Training
Phone: 3049106250
Email: hk00725@mygeorgiasouthern.edu

CITI Health Information Privacy and Security (HIPS) for Students and Instructors:

This course for **Students and Instructors** will satisfy the mandate for basic training in the HIPAA. In addition other modules on keeping your computers, passwords and electronic media safe and secure are included.

Stage 1. Basic Course Passed on 02/08/13 (Ref # 9590577)

Required Modules	Date Completed	
About the Course	02/06/13	1/1 (100%)
Privacy Rules: Introduction to Federal and State Requirements*	02/06/13	8/10 (80%)
Privacy Rules: Students and Instructors*	02/07/13	4/4 (100%)
Security Rules: Basics of Being Secure, Part 1*	02/07/13	no quiz
Security Rules: Basics of Being Secure, Part 2*	02/07/13	4/5 (80%)
Completing the Privacy and Security Course	02/07/13	no quiz
Elective Modules	Date Completed	
Security Rules: Protecting your Computer*	02/07/13	8/8 (100%)
Security Rules: Picking and Protecting Passwords**	02/08/13	5/8 (63%)

3) For this Completion Report to be valid, the learner listed above must be affiliated with a CITI participating institution. Falsified information and

unauthorized use of the CITI course site is unethical, and may be considered scientific misconduct by your institution.

4) Paul Braunschweiler Ph.D.
Professor, University of Miami
Director Office of Research Education
CITI Course Coordinator

NIH

